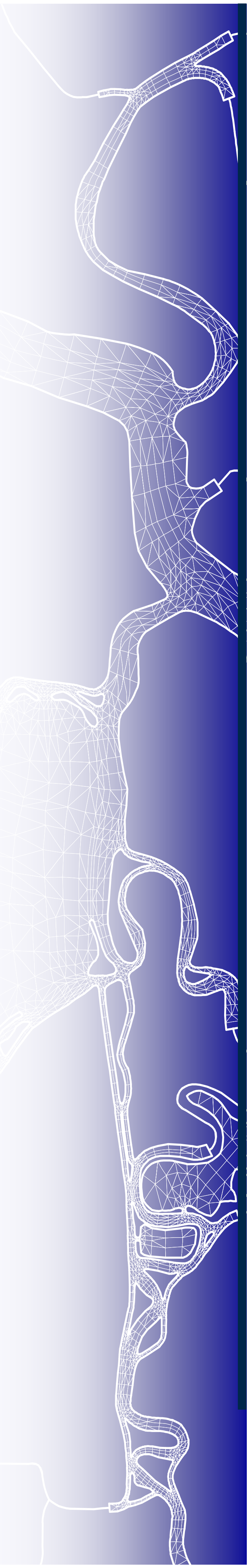
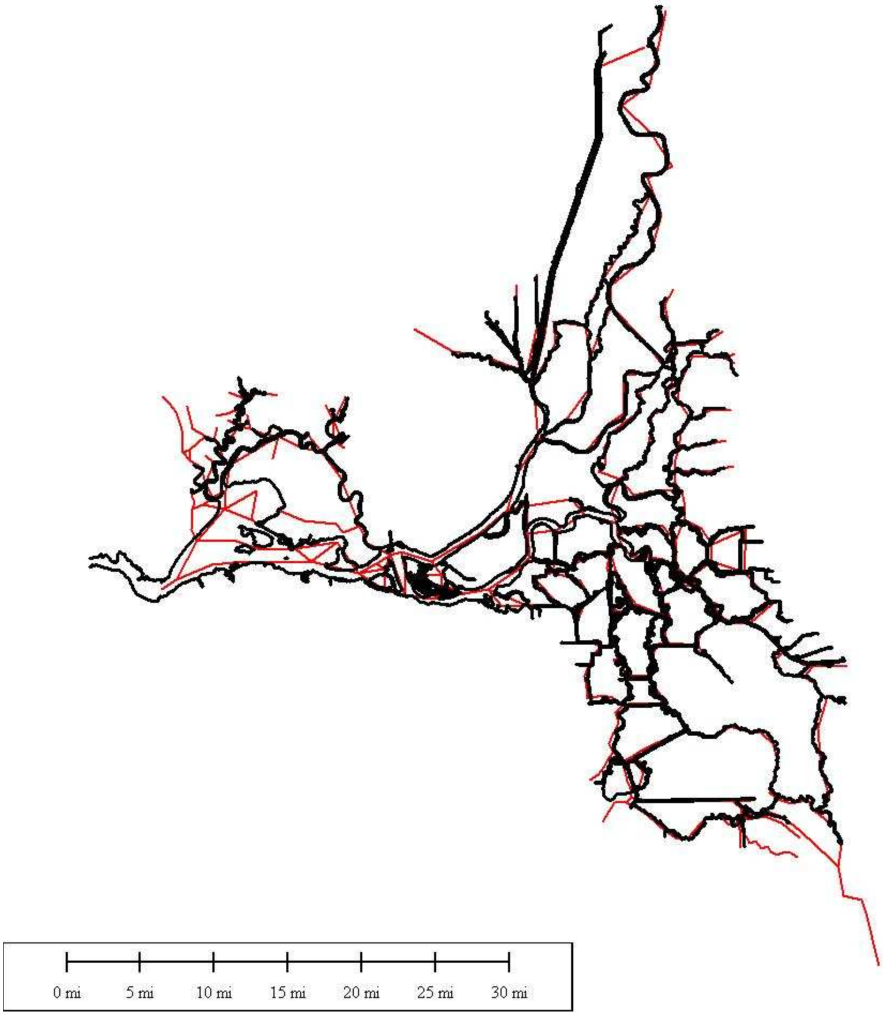
DWR-1037

MODELING THE FATE AND TRANSPORT OF AMMONIA USING DSM2-QUAL
DRAFT FINAL REPORT, OCTOBER 2009





Prepared For:
State Water Contractors
1120 L Street, Suite 1050
Sacramento, CA 95814

Contact:
Paul Hutton
Senior Engineer
Metropolitan Water District
916-650-2620

Prepared By:
Resource Management Associates
4171 Suisun Valley Road, Suite J
Fairfield, CA 94534

Contact: Marianne Guerin
707-864-2950

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1 Executive Summary

The Delta Simulation Model-2 water quality model, DSM2-QUAL, was used to model nutrient dynamics in the Delta. The modeled time frame was 1990 - 2008, the period covered by the DSM2 Historical model. The main goals of the project were to calibrate and validate DSM2-QUAL for temperature and nutrients with a focus on ammonia dynamics, to develop a prioritized monitoring program to fill data gaps and improve the understanding of nutrient dynamics in the Delta and to critique the existing model formulation. Several model scenarios and sensitivity analysis for some constituents are included in project results.

Data was needed to develop boundary conditions and to calibrate and validate the model for nine constituents (nutrients), and water temperature and meteorological data was needed to develop the temperature model. Data gathered from source agencies and individuals was evaluated for quality and accuracy, suspicious data was removed and gaps in data used for developing boundary conditions were filled.

Temperature and meteorological data had good spatial and temporal coverage over much of the modeled time span. Nutrient data was gathered for in-Delta measurements and for effluents from waste water treatment plants that release into the Delta. Most effluent data only covered recent years, while spatial and temporal coverage for in-Delta nutrient measurements was greatest 1990 – 1995.

The availability of data to develop boundary conditions for the nutrients dictated the level of accuracy in model results. Most in-Delta nutrient data came from grab samples at monthly or bi-weekly intervals, while water temperature and meteorological data was available hourly to daily. Measurement data gathered by the Environmental Monitoring Program (EMP) was used preferentially over other data sources. Long time series of data were available from EMP at or near most boundaries and the data was consistent with measurements from other data sources, and it was gathered by a single organization using a well-documented methodology. Data quality and documentation were very good. Several regions in the model domain were lacking data. In areas where there were few or no measurements, boundary conditions were set at reasonable levels to maintain calibration at downstream locations. There was no data available for the organic-P constituent.

Calibration was obtained by varying the minimal numbers of parameters needed to obtain an acceptable level of accuracy, as assessed by a set of calibration statistics. Calibration and validation statistics were calculated for all constituents (except organic-P) at a monthly time scale. Water temperature statistics were assessed on an annual basis using five hydrological year types from critically dry to wet. Nutrients were also assessed annually, but only using dry and wet year types.

Evaluation of the statistics indicates that the temperature model calibration is very good. The nutrient model in DSM2-QUAL has a simple conceptual formulation that proved sufficient for the task of modeling the 19-year frame over the entire Delta using data available only at a monthly time step. Calibration for the N-constituents, dissolved oxygen and chlorophyll a/algae was generally very good, except at a few locations. Calibration for the other constituents varied from very good to acceptable. Results were poorest where measurements were lacking or sparse.

The inclusion of new flow data available 2004 - 2008 at the Lisbon Toe Drain had a noticeable influence on nutrient dynamics and on volumetric contributions around Rio Vista and at downstream locations. Inclusion of a flooded Liberty Island in the DSM2 grid generally increased algal biomass at downstream locations and decreased concentrations of N-constituents.

Although the currently available data was sufficient to develop a nutrient model focusing on ammonia dynamics, the existing monitoring programs should be improved. The model constituent organic-P is not measured and carbonaceous biochemical oxygen demand (CBOD) was only measured in a few locations along the San Joaquin R. Some regions of the model do not have any coverage, and some areas have marginal coverage. The Yolo/Cache Slough area and portions of the eastern Delta need measurement locations as there are currently none. Suisun Marsh and the central Delta need additional measurement locations, as most of the data that is currently available ends in 1995.

The measurement time frame for the monitoring program will dictate the accuracy of the modeled constituents, so measurements need to be taken at a time scale commensurate with the quality of the desired results. Ancillary measurements should be taken along with the main constituents at infrequent intervals. For example, measurements to distinguish between dominant algal species and bacteria would help clarify the dynamics, and would inform the setting of model parameters QUAL. Finally, sediments should be sampled to help analyze possible contributions to nutrient dynamics from resident algae or macrophytes.

Several improvements are suggested for the conceptual model in QUSAL. Meteorological inputs need to be set on a regional basis to allow for variations across the model domain – this option is not currently available. One improvement in the model that would help clarify nutrient dynamics for ammonia is the inclusion of multiple algal groups, and an enhanced formulation for bacterial dynamics (most likely the inclusion of new constituent relationships). The model formulation proved inadequate to capture the effect of clams (*Corbula* and *Corbicula*). There are several possible approaches for improving the conceptual model to capture their effects on the food web. The most difficult area to improve in the model is the treatment of organic materials. Most changes would require a major overhaul of the conceptual model.

Because of the focus on ammonia in this project, the following terminology will be used: the term “ammonia” will refer to the combined amount of the two chemical species in solution NH_3

(*aq*) and NH_4^+. Where important for clarity, or where there is a need to discuss the distinct species, the terms ammonia or unionized ammonia are used to refer to NH_3 (*aq*) and the terms "ammonium" or "ammonium ion" are used to refer to NH_4^+. The reason for this choice of terminology is discussed in Section 4.2.2.

2 Project Objectives

The recent decline in the health of the San Francisco-San Joaquin Delta (Delta) ecosystems has increased the importance of understanding ecosystem function, and the linkages between ecosystem health and system drivers such as water temperature and nutrient levels. The complexity of these linkages presents a challenge that data analysis alone has not clarified, so conceptual and numerical models have been developed and used to increase our understanding of ecosystem functions.

The Delta Simulation Model-2, or DSM2, was used in this project to model the hydrodynamic and water quality interactions, including nutrient dynamics, in the Delta. DSM2 is a suite of models developed by California's Department of Water Resources (DWR). The hydrodynamic and water quality modules, HYDRO and QUAL, respectively, have been developed by DWR to model the historical conditions in the Delta from 1990 to 2008 – this implementation is called the "Historical Model". The calibration of the Historical Model has previously focused on simulating hydrodynamics and the transport of salinity, modeled as electrical conductivity (EC) and dissolved organic carbon (DOC). In this project, additional constituents in the conceptual model for QUAL were used to model the transport of nutrients and water temperature, with a focus on ammonia transport, as an extension of the base Historical Model implementation.

The main objectives of the work covered in this document are to: (1) calibrate and validate DSM2-QUAL to simulate temperature and nutrient interactions, with a focus on ammonia and nitrogen dynamics, in the model domain from 1990 - 2008, and (2) develop a prioritized water quality monitoring program with the intent of improving the understanding of ammonia and temperature dynamics in the Delta and improving the quality of the model calibration. In addition, the current conceptual model used in QUAL to simulate nutrient dynamics in the Delta is critiqued and potential modifications are suggested.

The project required the collection and synthesis of the large quantity of data needed to set the model boundary conditions over the 19 year time span, 1990 – 2008, and to calibrate and validate the model calculations for each of the eleven constituents conceptualized in QUAL to drive nutrient dynamics in the Delta. The description of the data, the methodology for transforming the data for modeling application, and summaries of data usage thus comprise a substantial portion of the documentation, as the quality of the model calibration is determined in large part by the availability and quality of the data. The adequacy of the conceptual model to simulate the nutrients dynamics is a function both of the model itself and of the data available to inform and constrain model boundaries and parameters in the underlying equations.

3 Background

3.1 DSM2 – general

DSM2 is a one-dimensional (1-D) hydrodynamic and water quality simulation model used to represent conditions in the Sacramento-San Joaquin Delta. The model was developed by the Department of Water Resources (DWR) and is frequently used to model impacts associated with projects in the Delta, such as changes in exports, diversions, or channel geometries associated with dredging in Delta channels. It is considered the official Delta water quality model, and as such it has been used extensively to model hydrodynamics and salinity as well as Dissolved Organic Carbon (DOC). Salinity is modeled as electrical conductivity (EC), which is assumed to behave as a conservative constituent.

The simplification of the Delta to a one-dimensional (1-D) model domain means that DSM2 can simulate the entire Delta region rapidly in comparison with higher dimensional models. Although many channels in the Delta are modeled well in 1-D, the loss of spatial detail in areas that are clearly multi-dimensional limit DSM2's accuracy in those areas.

DSM2 contains three separate modules, a hydrodynamic module (HYDRO), a water quality module (QUAL), and a particle tracking module (PTM). HYDRO was developed from the USGS FOURPT model (USBR, 2008). DWR adapted the model to the Delta, accounting for such features as operable gates, open water areas, and export pumps. The water quality module, QUAL, is based on the Branched Lagrangian Transport Model (Jobson, 1997), also developed by the USGS. QUAL uses the hydrodynamics simulated in HYDRO as the basis for its transport calculations. The capability to simulate nutrient dynamics and primary production in QUAL was developed by Rajbhandari (1995). The third module in the DSM2 suite is PTM, which simulates the fate and transport of neutrally buoyant particles. PTM also uses hydrodynamic results from HYDRO to track the fate of particles released at user-defined points in space and in time.

Detailed descriptions of the mathematical formulation implemented in the hydrodynamic module, DSM2-HYDRO and for salinity in the water quality module, DSM2-QUAL, the data required for simulation, calibration of HYDRO and QUAL, and past applications of the DSM2 Historical model are documented in a series of reports available at:

http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/annualreports.cfm.

Documentation on the calibration and validation of the modules used in the current implementation of the Historical model is available at that website. The calibration of HYDRO is assumed to be sufficient for our purposes, and areas where the model implementation is less accurate are discussed where relevant in the text.

3.2 Issues with ammonia and temperature in the Delta

In recent years, the community of pelagic fish and other pelagic organisms has experienced a severe decline in the Delta, a phenomenon now known as the “Pelagic Organism Decline”. High concentrations of ammonium ion (NH_4^+) have been identified by some researchers as potentially contributing to fish declines and poor phytoplankton growth in the Delta. Unionized ammonia (NH_3 (*aq*)) is known to be toxic to fresh water organisms (Randall and Tsui, 2002)), although the toxicity is dependent on pH and temperature. High ammonia levels may interfere with algal growth, as algae have been observed to utilize ammonia instead of nitrate when the concentration of ammonia is above 1 – 4 µmoles L^{-1} (Dugdale et al., 2007). Nitrate is used more efficiently by algae and algal growth rates are higher when nitrate is utilized instead of ammonia, all other things being equal.

Waste water treatment plants and agricultural drainage are known to contribute nitrogen-containing compounds in the Delta, along with other nutrients. Although nutrient loads from known sources are closely regulated to maintain beneficial levels for the identified uses of Delta waters, such as recreation and ecosystem health, there is uncertainty associated with the mandated levels and they are subject to re-regulation if new data suggests current levels are incorrect.

Water temperature is also a critical parameter regulating the functioning of the Delta ecosystem. Water temperatures in some areas can reach lethal levels for susceptible species inhabiting the Delta, such as delta smelt. Reaction rates for nutrient-related processes are generally temperature dependant. A combination of an over-abundant nutrient supply and optimal temperature for algal growth may result in algal blooms - the associated depleted dissolved oxygen levels can be lethal to some aqueous inhabitants. Alternatively, if nutrient levels are poor or unbalanced, as may occur if ammonium levels are too high, algal growth may be inhibited even at optimal temperatures. As algae form a basis for the food supply for higher level organisms, if algal growth is inhibited the supply of food for higher level organisms from zooplankton to fish is also limited. If this occurs in areas where fish populations are dependent on a source of food, such as the areas in and around Suisun Bay, the result may eventually be a decline in the population.

3.3 Previous nutrient models using DSM2

Previous uses of QUAL to simulate nutrient dynamics in the Delta focused on dissolved oxygen (DO). Rajbhandari (2000, 2001, 2003, 2004, and 2005) used QUAL to model DO dynamics on the San Joaquin River, addressing concerns about low DO in the vicinity of Stockton. Subsequently, the application and area of calibration were extended to the San Joaquin Deep Water Ship Channel. The final application focusing on DO extended model development to a wider region of the Delta to support technical studies for the In-Delta Storage Project Feasibility Study. This model study assessed the potential impact of the project on temperature and DO levels using CALSIM II (Rajbhandari, 2004)) output for the hydrological conditions in the 16-year scenarios (1975 – 1991). This type of study is an example of a Planning Study in which DSM2 is used to quantify the effects a modification in the Delta water regime, such as construction of a new gate, may have on hydrodynamics and water quality. DSM2 Planning models currently cover the period from 1922 to 2003 using CALSIM II simulated hydrology.

3.4 Additional analysis – aqueous geochemistry and isotopes

Additional modeling analysis using the aqueous geochemical model EQ3/6 (Wolery, 1992) was performed to establish a baseline for chemical speciation in the waters at the two main model boundaries on the Sacramento and San Joaquin Rivers. As discussed in Section 4.2.2, QUAL's nutrient model does not include chemical speciation, knowledge of which can give important insight into the detailed chemical interactions among the constituents in the water. The EQ3/6 analysis is discussed in Section 9.1.

The results of a collaborative effort between this project and C. Kendall to use isotopic data to inform and constrain the DSM2 nutrient model are documented in Section 9.2. Isotope data can be used to identify sources of nutrients and dominating processes involved in their transformation, and the collaboration is combining DSM2 QUAL results with results from isotopic analyses. The distinctive isotope "fingerprints" are more diagnostic than standard chemical measurements to sources and sinks of various materials which can often be identified, traced, and semi-quantified using stable isotopes. For example, nitrate derived from animal waste is isotopically distinguishable from nitrate derived from inorganic fertilizer, and organic matter derived from algae is isotopically distinguishable from organic matter derived from terrestrial plants. Different kinds of sinks (biogeochemical removal mechanisms) sometimes cause distinctive shifts in isotopic compositions. For example, nitrification and assimilation cause predictable and distinctive changes in isotopic composition.

4 Model Configuration

The implementation of the DSM2 modules HYDRO and QUAL discussed in this report extends the standard configuration of the "Historical Model", which simulates historical conditions in the Delta from 1990 – 2008, by including effluent flows from most of the wastewater treatment plants (WWTPs) with outfalls within or just outside of DSM2's model domain in the Delta. Although the volume of these effluent inflows is small in comparison with other inflows to the Delta, they are important sources of the nutrients modeled in QUAL.

4.1 Model Grid

The DSM2 model grid is shown in Figure 17-2. The grid consists of one-dimensional channels, indicated by red lines, linked by nodes, indicated by black symbols, and open water areas whose approximate locations are indicated by blue numbers. Open water areas are modeled as well-mixed reservoirs.

4.2 Model Boundaries

4.2.1 Flow and Stage Boundaries

Boundaries that define the movement of water into and out of the Delta consist of inflow boundaries, outflow boundaries and a stage boundary set at Martinez (Figure 4-1). Exports and diversions remove water from the model – water also flows out of the model at its downstream boundary, the stage boundary at Martinez In addition, there are structures in the model, such as gates and weirs, that are operated to control flow, stage or the transport of salinity that simulate the actions of these structures in the Delta.

In Figure 4-2, the main inflow boundaries are denoted by blue stars. These boundaries are found at the each of the major rivers (Sacramento, San Joaquin, Calaveras, Mokelumne and Cosumnes), and at the Yolo Bypass and the Lisbon Toe Drain (in the Yolo region). The Yolo boundary only has inflow during periods of high Sacramento River inflow which can occur in the late fall through early spring. Flows at the Lisbon Toe Drain near Liberty Island on the north western edge of the Delta, normally not included in HYDRO, were added when available as some effluent sources eventually enter the model domain at that point. Flow data for the Lisbon Toe Drain was available starting in 2004.

Figure 4-2 shows the location of effluent inflow boundaries discussed in this report. The volume of effluent water is small in comparison with other inflow contributions (see Section 11.1) except in periods of very low inflow.

The effects of evaporation, precipitation, and channel depletions and additions ascribed to agricultural influences and are modeled using the Delta Island Consumptive Use (DICU) model[1]. This model is used to set boundary conditions at 258 locations throughout the Delta – these locations are subdivided into 142 regions. DICU boundary conditions vary monthly and are set by Water Year Type. The uncertainty in the estimates of DICU inflow, outflow and constituent concentrations is high. During periods of low inflow, errors in volumes ascribed to DICU boundaries may dominate model results.

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[1] http://www.iep.ca.gov/dsm2pwt/reports/DSM2FinalReport_v07-19-02.pdf, http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/models/dicu/DICU_Dec2000.pdf

4.2.2 Transport Model Boundaries – Nutrients, salinity and temperature

Each inflow boundary type, including DICU and effluent boundaries, is also a boundary for transported constituents. There are eleven equations in the transport model, nine of which are called "nutrients" in this report, plus one equation for salinity and one equation for temperature. Water temperature plays an important role in nutrient dynamics but (clearly) has no mass, while each of the other ten equations in the model represents a constituent with mass. Salinity is important in modeling dissolved oxygen saturation, as an increase in salinity can decrease DO saturation. Salinity generally only plays an important role at the Martinez boundary but otherwise does not play a direct role in nutrient dynamics in the model.

The temperature transport equation requires data for barometric pressure, air temperature, wet bulb temperature, wind speed and cloud cover. Meteorological conditions are used in modeling the exchange of heat at the air-water interface in the formulation of the heat transport equation. Modeled water temperature plays a role in the rate of each constituent reaction. Atmospheric pressure is used in modeling the saturation of dissolved oxygen in water, along with other conditions such as water temperature, salinity and reaeration.

The current model formulation only allows for a single meteorological region for the entire model domain. As discussed in Section 8.8.3 (setting boundary conditions) and in Section 10.2 (temperature calibration), this has proved to be a disadvantage in the simulation of modeled water temperature in DSM2.

4.3 Previous calibration

The DSM2 module HYDRO was recalibrated for flow and stage by DWR and the Interagency Ecological Program's Project Work Team in 2003[2]. QUAL was most recently recalibrated for salinity in 2000. Salinity is modeled using EC in QUAL, under the assumption that EC can be approximated as a conservative substance, and so is used as a surrogate for salinity in the model. Calibration was conducted for 4 separate periods, three spring events (May 1998, April 1997, April 1998) and one fall event (September and October 1988). The hydrodynamic calibration effort made use of tidal flow meter data and measured stages. Roughness coefficients were adjusted to improve the ability of the model to reproduce measured stage and flow.

The water quality model was calibrated for salinity with the use of extensive EC measurements throughout the Delta. A three year period (October 1991 to September 1994) was used for the calibration. Unlike the hydrodynamic calibration, a single time period was required because the system is strongly influenced by recent salinity conditions. Reproduction of measured EC values was accomplished by adjusting dispersion coefficients throughout the system.

[2] http://www.iep.ca.gov/dsm2pwt/

The nutrient model in QUAL was calibrated on the San Joaquin River, approximately between Vernalis and Prisoner's Point for the period 1996 – 2000 (Rajbhandari, 2001). The main application of this modeling effort was simulating problems with DO concentration in the region near the Stockton Deep Water Ship Channel (SDWSC). This effort is documented in several DWR reports, including (Rajbhandari, 2001) and (Rajbhandari, 2003). An additional DO model application of the nutrient model for planning purposes is documented in (Rajbhandari, 2004).

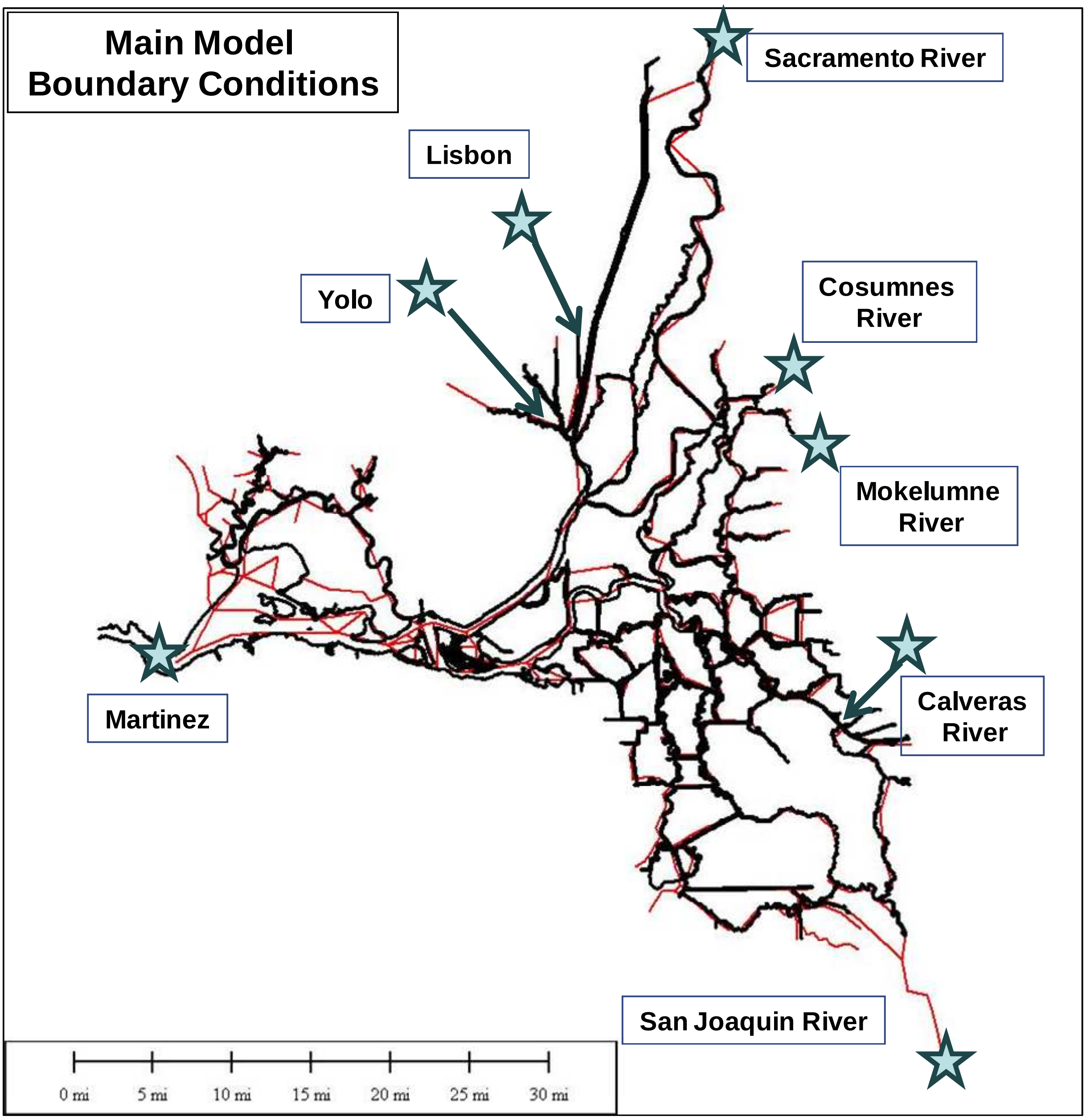


Figure 4-1 Approximate location of the model inflow boundaries (blue stars). The stage boundary is at Martinez.

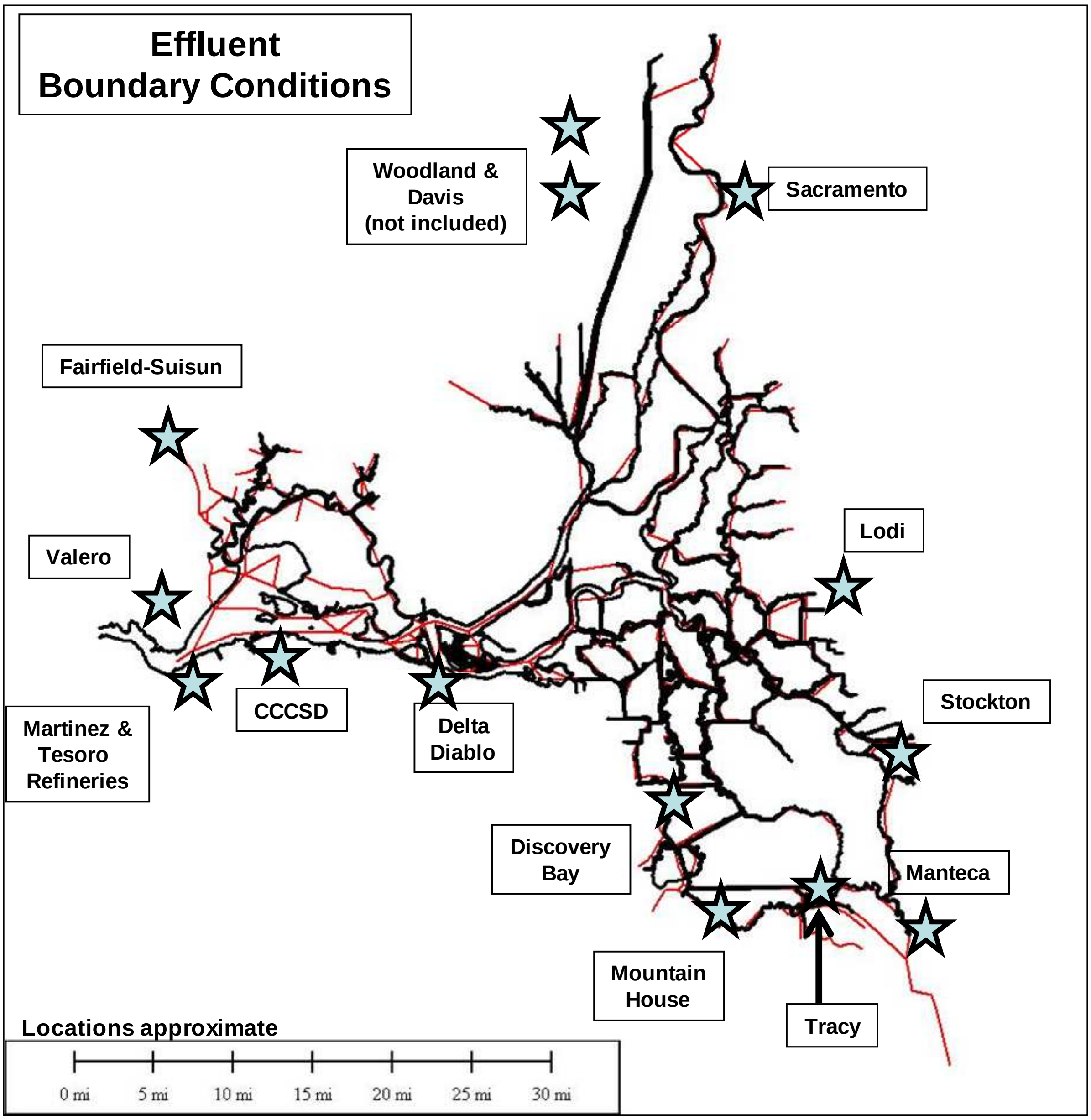


Figure 4-2 Approximate locations of effluent boundary conditions for waste water treatment plants considered in this report.

5 Conceptual Model for Nutrient Dynamics

5.1 Background

Figure 5-1 is a conceptualization of the interactions between the main constituents used to model nutrient dynamics in the QUAL mass transport model - this figure is an adaptation of figures shown in (Rajbhandari, 2003). Each box (or oval) in the blue region (water) symbolizes one of the nine equations for non-conservative constituents in the transport model. There are equations for dissolved oxygen (DO), nitrate (NO_3), nitrite (NO_2), ammonia (NH_3), organic-N, carbonaceous biochemical oxygen demand (CBOD), orthophosphate (PO_4, dissolved-P in the Figure), organic-P, and algae. Chlorophyll a (chl-a) measurements are used to calculate the biomass of algae in the model. Salinity is modeled as a conservative constituent - it is not included in Figure 5-1.

Arrows in Figure 5-1 indicate a relationship, modeled as a temperature-dependent reaction rate, between two variables or for adding or removing mass into or out of the model calculation for a given constituent, respectively. Water temperature influences the dynamics of the constituent interactions as a factor in the rate of reactions - an increase in water temperature results in a change, generally an increase, in reaction rates. Conversely, modeled DO saturation decreases with increased temperature.

Although each of the constituents occurs in an ionized form in aqueous solutions, charges on the constituents are not used in the model or in this report except where specifically indicated. In reality, each constituent occurs in a suite of sub-species in solution with variable charge and potentially associated with many other aqueous species. As this level of interaction is not explicitly accounted for QUAL, no single charge can be legitimately assigned.

An important distinction needs to be made between term “ammonia” and the concentrations of each of the chemical species NH_3 and NH_4^+. NH_3 occurs naturally as a gas that is dissolved in the aqueous phase, but the gas is also ionized to NH_4^+, *i.e.* ammonium, in a pH-dependent reaction in solution. At neutral pH (pH = 7.0), the majority of the “ammonia” in solution occurs in its ionized form as NH_4^+. For example, at a water temperature of 25°C the equilibrium reaction constant, $\log_K$, for the aqueous association reaction yields that approximately 50% of the “ammonia” occurs as NH_4^+ at pH 9.5. The amount of NH_4^+ increases with decreasing pH, so that at pH 8.5 only about 9% of the ammonia is present in its unionized (NH_3) form. In most of the Delta, the pH is typically less than pH 8.5 except for episodic, localized increases. Further detail on these calculations is found in Appendix Section 17.10.

Because QUAL does not explicitly model pH and cannot distinguish between the unionized and ionized forms, the term “ammonia” is used in this report to indicate the total concentration[3] of $[NH_3] + [NH_4^+]$. A simplifying assumption in interpreting model results is that the majority of the “ammonia” concentration reported in calculations is occurring in the ionized “ammonium” form. Measured data collected for setting boundary conditions and as calibration/validation data is generally reported by the collecting agency as “ammonia”, and is actually reporting the total $[NH_3] + [NH_4^+]$.

The conceptual model for each constituent is discussed in greater detail in the following sections.

5.2 Nutrient Model formulation

The ten equations that comprise the nine non-conservative constituents in the nutrient model plus temperature are discussed individually below. The equation for salinity, the conservative constituent, is not discussed. Each mass balance equation represents the mass per unit volume of water. The transport of the constituent due to advection is not shown due to the assumption of a Lagrangian reference frame that moves through the domain at the mean velocity of the water - additional information can be found in (Rajbhandari, 1995a and 1995b).

Table 5-2 and

Table 5-3 detail the 47 adjustable parameters that are used in the equations. Some of the symbols appearing in the Tables do not appear explicitly in the equations. Parameters that appear in the equations that are not listed in the Tables are defined at their initial appearance in the text.

There are sixteen temperature coefficients for reaction rates shown in

Table 5-3. Temperature coefficients are defined by the relationships $k(T) = k(20)\Theta^{(T-20)}$, where k(T) is the reaction rate day^{-1} at temperature T in °C and Θ is the user-defined temperature coefficient for the reaction shown in the Table. The values used for these coefficients were set at standard literature values.

[3] Unlike the convention in aqueous chemistry, square brackets are used to symbolize the concentration of an aqueous species (not the activity) in solution. The units of concentration are understood to be the units in the model unless specifically stated otherwise.

Table 5-1Definitions for variables appearing in equations 1 – 10.

Variable Symbol	Modeled Constituent
O	DO
L	CBOD
NH_3	Total ammonia as N
NO_2	Nitrite as N
NO_3	Nitrate as N
A	Phytoplankton biomass
N-org	Organic nitrogen
P-org	Organic phosphorus
PO_4	Orthophosphate as P
T	Temperature

5.2.1 Temperature

The formulation for the transport of temperature in the model, equation (1) was adapted from the QUAL2E model (Brown and Barnwell, 1987), with several changes documented in (Rajbhandari, 1995b). Water temperature influences the interactions between the modeled constituents as discussed in the overview to this Section.

The net transfer of energy, Q_n, across the air-water interface is formulated as a function of net short wave radiation flux, net long wave atmospheric radiation flux, water surface back radiation flux, evaporative heat flux and sensible heat flux. The expressions accounting for this energy transfer are functions of the meteorological inputs (not shown). In the equation, p is the density of water, C is the specific heat of water and d is the hydraulic depth of the water. E_x is the longitudinal dispersion coefficient.

$$\frac{\partial[T]}{\partial t} = \frac{\partial}{\partial \xi}\left[E_x \frac{\partial T}{\partial \xi}\right] + Q_n \big/ pcd \quad \textbf{(1)}$$

5.2.2 Dissolved Oxygen (DO)

DO concentration is a critical indicator of the general health of an aquatic ecosystem (Rajbhandari, 1995a; Cole and Wells, 2008). Equation (2) specifies the rate of change in DO concentration due to sources (reaeration and photosynthesis), sinks (CBOD, oxidation of NH_3 and NO_2, algal respiration and benthic demand) and dispersion. The expressions used to model DO saturation and reaeration are discussed in detail in (Rajbhandari, 1995a).

Benthic oxygen demand represents a generic expression encompassing several processes in the sediment that remove oxygen from the water column, including the decay of organic matter and utilization of dissolved oxygen by benthic species (such as clams) and macrophytes.

$$\frac{\partial[O]}{\partial t}=\frac{\partial}{\partial\xi}\left[E_x\frac{\partial[O]}{\partial\xi}\right]-(k_1+k_3)L+k_2(O_s-[O])-\alpha_5k_n[NH_3]-\alpha_6k_{ni}[NO_2]+\alpha_3\mu[A]-\alpha_4\rho[A]-{K_4}/{d} \quad (2)$$

Diffusion CBOD Reaeration Ammonia ox. Nitrite ox. Photosynthesis Respiration Benthic

5.2.3 Carbonaceous Biochemical Oxygen Demand (CBOD)

Carbonaceous biochemical oxygen demand refers to the potential for microorganisms to consume oxygen as they utilize organic-carbon substrates. A related measurement is nitrogenous BOD (NBOD) – this refers to the oxygen consumed by nitrifying bacteria as they consume organic and inorganic materials that contain a reduced form of nitrogen. Collectively, CBOD+NBOD is called BOD, and tests that measure any of the three forms occur over a number of days, typically five or twenty days. For the purposes of this project, we utilized $CBOD_5$, a five-day test for CBOD. Further detail is found in the Appendix I Section 17.3.

Equation 3 accounts for the sources and sinks of CBOD due to the death of algae or oxidation, respectively.

$$\frac{\partial[L]}{\partial t}=\frac{\partial}{\partial\xi}\left[E_x\frac{\partial[L]}{\partial\xi}\right]-(k_1+k_3)L+\sigma_6[A] \quad (3)$$

5.2.4 Algae (Phytoplankton)

Equation 4 accounts for the biomass of algae in the model. Algae utilize chlorophyll pigments to convert solar radiation to energy, and chlorophyll a (a particular form of pigment) measurements are typically used as an indicator of algal biomass. A conversion factor is used to convert chlorophyll a concentrations to algal biomass. For this project, we used a conversion factor of 67 g algae/mg chl-a (Clesceri et al., 1999), although there are many different algal species (Cole and Wells, 2008) with variable characteristics including growth rates, preferred nutrient sources, and levels of chlorophyll per unit of mass.

$$\frac{\partial[A]}{\partial t}=\frac{\partial}{\partial\xi}\left[E_x\,\frac{\partial[A]}{\partial\xi}\right]+(\mu-\rho)[A]\ -\sigma_1[A]/d-\sigma_6[A] \quad \textbf{(4)}$$

Algal growth is a function of the difference between the respiration rate, ρ, and the growth rate, μ, of this generic algal population. The growth in algal biomass is assumed to be limited by availability of light, F_L, inorganic nitrogen, N, as the sum of the concentrations of NH_3 and NO_3, and inorganic phosphorus, P, as expressed in the following equation (4a):

$$\mu=\mu_{MAX}\ F_L\ Min\left(\frac{N}{K_N+N},\frac{P}{K_P+P}\right) \quad \textbf{(4a)}$$

where K_N and K_P are the half-saturation constants of nitrogen and phosphorus, respectively. F_L is further expressed as a Monod equation as a function of light intensity at a given depth (Rajbhandari, 1995a).

As shown is subsequent sections, the generic algal biomass is assumed to be composed of a set ratio of N:P concentrations, although this ratio can vary between different algal species.

5.2.5 Organic nitrogen (Org-N)

Organic nitrogen dynamics are represented by equation 5:

$$\frac{\partial[N-org]}{\partial t}=\frac{\partial}{\partial\xi}\left[E_x\,\frac{\partial[N-org]}{\partial\xi}\right]+\alpha_1\,\rho[A]-k_{N-org}[N-org]-\sigma_4[N-org] \quad \textbf{(5)}$$

The only source of nitrogen due to nutrient dynamics occurs as a result of algal respiration as a fraction of the algal biomass assumed to be nitrogen. Org-N is lost from the system as it decays and settles.

Because organic-N measurements are frequently unavailable, Total Kjeldahl Nitrogen (TKN) can be used to calculate organic-N if ammonia measurements are also available, as TKN = organic-N + ammonia.

5.2.6 Ammonia (NH_3)

Ammonia nitrogen dynamics are represented by equation 6:

$$\frac{\partial[NH_3]}{\partial t}=\frac{\partial}{\partial\xi}\left[E_x\,\frac{\partial[NH_3]}{\partial\xi}\right]-f\,\alpha_1\mu[A]+k_{N-org}[N-org]-k_n[NH_3]+\sigma_3/d \quad \textbf{(6)}$$

Although ammonia concentration is represented in this equation by the formula NH_3, in fact the concentration of ammonia is assumed implicitly to be the total of aqueous NH_3 (g) and NH_4^+, as discussed previously. NH_3 is a nutrient source for algae, as is NO_3, and the preferential consumption of these two sources of nitrogen is given by a preference factor, $0.0 \le p \le 1.0$, in the following expression:

$$f = \frac{p[NH_3]}{p[NH_3] + (1-p)[NO_3]} \quad \textbf{(6a)}$$

where the square brackets indicate modeled concentration.

5.2.7 Nitrite (NO_2)

In equation 6, NH_3 is seen to decay at a set rate – in equation 7 we see that that the NH_3 has decayed into NO_2:

$$\frac{\partial[NO_2]}{\partial t} = \frac{\partial}{\partial \xi}\left[E_x \frac{\partial[NO_2]}{\partial \xi}\right] - k_{ni}[NO_2] + k_n[NH_3] \quad \textbf{(7)}$$

5.2.8 Nitrate (NO_3)

Nitrate dynamics are given by equation 8. Here we see that NO_2 has decayed into NO_3:

$$\frac{\partial[NO_3]}{\partial t} = \frac{\partial}{\partial \xi}\left[E_x \frac{\partial[NO_3]}{\partial \xi}\right] - (1-f)\alpha_1 \mu [A] + k_{ni}[NO_2] \quad \textbf{(8)}$$

Nitrate is consumed by algae, where the rate is assumed to be governed by the preference of algae for NH_3 or NO_3.

5.2.9 Organic Phosphorus (Org-P)

Equation 9 shows the sources and sinks for org-P in the nutrient dynamics:

$$\frac{\partial[P-org]}{\partial t} = \frac{\partial}{\partial \xi}\left[E_x \frac{\partial[P-org]}{\partial \xi}\right] + \alpha_2 \rho [A] - k_{P-org}[P-org] - \sigma_5[P-org] \quad \textbf{(9)}$$

5.2.10 Dissolved Phosphorus (PO_4)

The final equation represents the sources and sinks of inorganic phosphorus, which is assumed to the concentration of ortho-phosphate, PO_4:

$$\frac{\partial[PO_4]}{\partial t} = \frac{\partial}{\partial \xi}\left[E_x \frac{\partial[PO_4]}{\partial \xi}\right] - \alpha_2 \mu [A] + k_{P-org}\,[PO_4] + \sigma_2 / d \quad \textbf{(10)}$$

5.2.11 Reaction Rates and Parameters

There are 16 Regional Reaction Rate parameters (Table 5-2 and Table 5-3) that can that can be varied by channel in the grid as well as in each open water body (reservoir). There are 31 Global Reaction Parameters that are set for the entire model domain. The sixteen temperature coefficients for reaction rates (Table 5-3) are set globally. The values listed in the "Calibrated Values" column give the ranges set in the model.

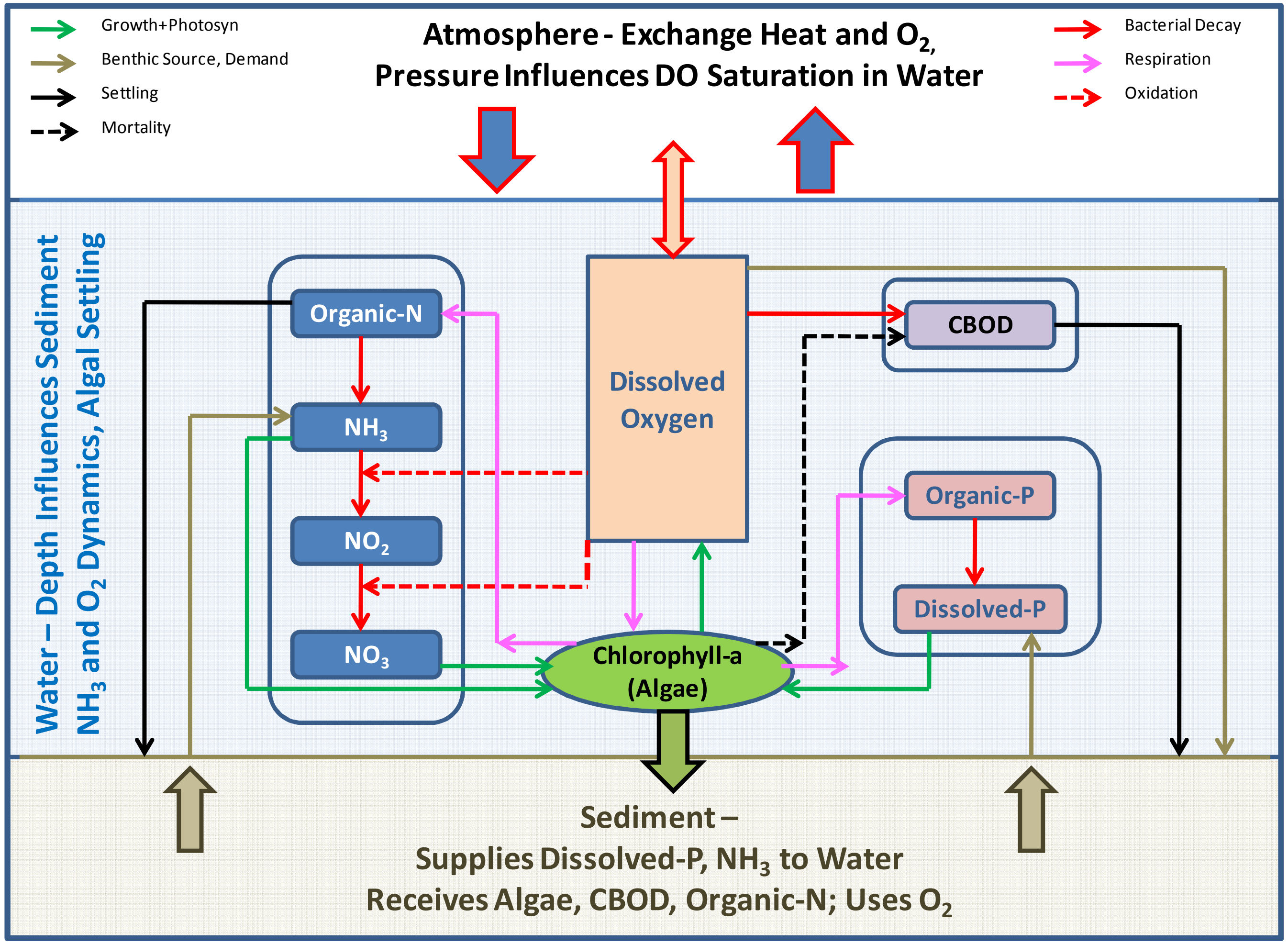


Figure 5-1. The interactions between main constituents, and external influences (an adaptation from original DWR references). Water temperature (blue region) influences reaction rates, denoted by arrows.

Table 5-2 Parameters used in the model equations

Symbols	Description	Lit. Range Min/Max	Calibrated Values	Units	Source
k_{ni}	Nitrite decay rate at the ambient temperature	0.2-2.0	2.0	day^{-1}	Rajbhandari (1995)
$k_n + k_{ni}$	Ammonia decay rate + Nitrite decay rate at the ambient temperature	0.001-1.3	-	day^{-1}	Bowie et al. (1985)
k_{n-org}	Rate constant for hydrolysis of organic nitrogen to ammonia nitrogen at the ambient temperature	0.02-0.4	0.1	day^{-1}	Rajbhandari (1995)
σ_4	Organic nitrogen settling rate at the ambient temperature	0.001-0.1	0.0 - 0.01	day^{-1}	Rajbhandari (1995)
k_{p-org}	Organic phosphorus decay rate at the ambient temperature	0.01-0.7	0.05 - 0.1	day^{-1}	Rajbhandari (1995)
σ_5	Organic phosphorus settling rate at the ambient temperature	0.001-0.1	0.0 – 0.9	day^{-1}	Rajbhandari (1995)
σ_2	Benthic release rate for orthophosphate at the ambient temperature (mass transfer rate of $PO4$ in the sediment)	1.0 0.0816 0.057–21.0	0.0 - 0.1	$mg\ m^{-2}\ day^{-1}$ $m\ day^{-1}$ $mg\ m^{-2}\ day^{-1}$	Rajbhandari (1995) Sanford and Crawford(2000) Cole & Wells (2008)
σ_3	Benthic release rate for ammonia-N at the ambient temperature (mass transfer rate of $NH3$ in the sediment)	4.0 0.06-0.1464	0.0-0.14	$mg\ m^{-2}\ day^{-1}$ $m\ day^{-1}$	Rajbhandari (1995) Sanford and Crawford(2000) Cole & Wells (2008)
k_4	Benthic oxygen demand	30 – 300 0.3 – 5.8	30 - 300	$g\ m^{-2}\ day^{-1}$ $g\ m^{-2}\ day^{-1}$	Rajbhandari (1995) Chapra (1997)
Temperature Coefficients for Reaction Rates					
$\theta(1)$	BOD decay	1.047 1.02	1.047		Wilson et al. (1998) Cole & Wells (2008)
$\theta(2)$	BOD settling	1.024	1.024		Wilson et al. (1998)
$\theta(3)$	DO Reaeration	1.024	1.024		Wilson et al. (1998); Chapra (1997)
$\theta(4)$	DO SOD	1.060 1.04-1.13	1.06		Wilson et al. (1998) Cole & Wells (2008)
$\theta(5)$	Organic-N decay	1.047	1.047		Wilson et al. (1998)
$\theta(6)$	Organic-N settling	1.024	1.024		Wilson et al. (1998)
$\theta(7)$	Ammonia-N decay	1.083	1.083		Wilson et al. (1998)
$\theta(8)$	Ammonia-N benthic source	1.074	1.074		Wilson et al. (1998)
$\theta(9)$	Nitrite-N decay	1.047	1.047		Wilson et al. (1998)
$\theta(10)$	Organic-P decay	1.047	1.047		Wilson et al. (1998)
$\theta(11)$	Organic-P settling	1.024	1.024		Wilson et al. (1998)
$\theta(12)$	Dissolved-P benthic source	1.074	1.074		Wilson et al. (1998)
$\theta(13)$	Algae growth	1.047	1.047		Wilson et al. (1998)
$\theta(14)$	Algae respiration	1.047	1.047		Wilson et al. (1998)
$\theta(15)$	Algae settling	1.024	1.024		Wilson et al. (1998)
$\theta(16)$	Algae death	1.047	1.047		Wilson et al. (1998)
θ_{rxn}^{T-20}	the non-dimensional temperature multipliers of reaction	1.045-1.08			Bowie et al. (1985)

Table 5-3 More equation parameters

Symbols	Description	Lit. Range Min/Max	Calibrated Value	Units	Source
Global Reaction Parameters					
α_5	Amount of oxygen consumed in conversion of ammonia to nitrite	3.0-4.0	3.0	-	Rajbhandari (1995)
α_6	Amount of oxygen consumed in conversion of nitrite to nitrate	1.0-1.14	1.14	-	Rajbhandari (1995)
p	Preference factor for ammonia nitrogen	0-1.0	0.5	-	Rajbhandari (1995)
α_7	Conversion factor	10-100	14.9	μg-Chla mg^{-1}	Rajbhandari (1995)
α_1	Fraction of algal biomass, which is nitrogen	0.07-0.09 0.02-0.11	0.09	-	Rajbhandari (1995) Cole & Wells (2008)
α_2	Fraction of algal biomass, which is phosphorus	0.01-0.02 0.001-0.03	0.012	-	Rajbhandari (1995) Cole & Wells (2008)
α_3	Amount of oxygen produced per unit of algal photosynthesis	1.4-4.8	1.60	-	Rajbhandari (1995)
α_4	Amount of oxygen consumed per unit of algal respired	1.6-2.3	2.0	-	Rajbhandari (1995)
K_L	Half saturation constant for light	0.02-0.1	0.085	Kcal m^{-2} s^{-1}	Rajbhandari (1995)
K_N	Half saturation constant for nitrogen	0.01-0.3 0.01–4.3	0.05	mg L^{-1}	Rajbhandari (1995) Cole & Wells (2008)
K_P	Half saturation constant for phosphorus	0.001-0.05 0.001-1.5	0.035	mg L^{-1}	Rajbhandari (1995) Cole & Wells (2008)
λ_0	Non-algal portion of the light extinction coefficient	0.116	0.26	ft^{-1}	Rajbhandari (1995)
λ_1	Linear algal self shading coefficient	0.002-0.02	0.003	ft^{-1} (μg-Chla L^{-1})$^{-1}$	Rajbhandari (1995)
λ_2	Nonlinear algal self shading coefficient	0.0165	0.0165	ft^{-1} (μg-Chla L^{-1})$^{-2/3}$	Rajbhandari (1995)
λ_3	Algal mortality contribution to BOD	1.0	1.0	day^{-1}	Rajbhandari (2002)
Regional Reaction Rates					
k_1	CBOD decay rate at the ambient temperature	0.02-3.4 0.01 – 0.06 ?	0.12	day^{-1}	Rajbhandari (1995) Cole & Wells (2008)
k_3	Rate of loss of CBOD due to settling at the ambient temperature	-0.36-0.36	0.1	day^{-1}	Rajbhandari (1995)
μ_{max}	Maximum growth rate at the ambient temperature	1.0-3.0	1.0 - 3.0	day^{-1}	Rajbhandari (1995)
ρ	Phytoplankton respiration rate at the ambient temperature	0.05-0.5 0.01-0.04	0.15	day^{-1}	Rajbhandari (1995) Cole & Wells (2008)
σ_1	Phytoplankton settling rate at the ambient temperature	0.5-6.0 0.06-33.0	0.2 – 1.5	ft day^{-1}	Rajbhandari (1995) Cole & Wells (2008)
σ_{21}	Phytoplankton death rate at the ambient temperature	0.2 0.03-0.3	0.11 – 0.7	ft day^{-1}	Rajbhandari (2002) Cole & Wells (2008)
k_n	Ammonia decay rate at the ambient temperature Ammonium decay rate	0.1-1.0 0.001 – 0.95	0.05 - 0.20	day^{-1}	Rajbhandari (1995) Cole & Wells (2008)

6 Data Sources and Data Refinement

Several data sources were identified for data needed in the development of boundary conditions and for the model calibration and validation effort. Data quality was assessed and several approaches were used to improve the representation of the data. Details on the data sources and the data gathered for the entire modeling effort are covered in Appendix Section 17.2.

Constituent concentration data was reported in a variety of measurement units depending on data source. Reported concentrations were converted to units of mg L^{-1}, the measurement unit used in QUAL, in terms of the molecular weight the atom characterizing the chemical species. For example, the concentration of orthophosphate, PO_4, is calculated as milligrams of PO_4-P, not in terms of the molecular weight of the entire species (i.e., without accounting for the weight of the oxygen atoms in the chemical species).

6.1 Data Sources

Raw data were downloaded from the BDAT[4], DWR's Water Data library[5], IEP[6], CDEC[7] and USGS[8] websites. Meteorological data were downloaded from the CIMIS[9] website, and access to NOAA meteorological data were purchased and downloaded from NOAA (NNDC Online Store, NOAA data Center). Some data were obtained directly from individual researchers or from individuals identified as representing an organization. Effluent data were obtained from sources in the Central Valley and San Francisco Regional Water Quality Control Boards, directly from contacts at the individual waste water treatment plants, or from previous compilations of effluent data. Measurements upstream and downstream of effluent outfalls, called receiving water measurements, were collected when available. All data sources obtained from individuals in any of these ways (i.e., not downloaded directly from a publically available database) are documented in Section 17.2 in Appendix I.

[4] http://bdat.ca.gov/

[5] http://www.water.ca.gov/waterdatalibrary/

[6] http://www.iep.ca.gov/data.html

[7] http://cdec.water.ca.gov/

[8] http://sfbay.wr.usgs.gov/access/wqdata/

[9] http://wwwcimis.water.ca.gov/cimis/welcome.jsp

6.2 Data processing methodology

Measurement unit and data measurement methodology were checked in each data set for consistency with DSM2 model assumptions. Latitude-longitude (lat-long) co-ordinates were obtained to verify the position of the data acquisition location and to ensure appropriate placement in the model. Data downloaded from the BDAT website, lat-long co-ordinates of the measurement location, and the name used in model calculations are documented in Table 17-2 through Table 17-4 in Appendix Section 17.2. Raw data were downloaded either in EXCEL format, CSV format, tabular text format, or in some cases, was downloaded in DSS format directly to the program HEC-DSSVue[10].

Data obtained in anything other than DSS format required further processing for use in setting model boundaries, as DSM2 uses the DSS data format (employed in HEC-DSSVue) for importing the data into model simulations. MATLAB codes and other data processing tools were developed to automate much of the transfer to DSS format. Irregular time series data were further processed into regular time series data for use in setting boundary conditions, typically as daily data with linear interpolation between the irregularly-spaced data points. Processing irregular data into regular time series was not necessary for plotting or for residual calculations.

6.3 Data Quality

Data quality was mixed, depending on the constituent. All data were assessed visually (by plotting) to check for unreasonable values (*e.g.,* negative numbers) and in comparison with data at nearby locations. When problems with data quality clearly occurred (*e.g.,* all nearby stations had significantly different magnitudes), suspect data were deleted from the time series.

Continuous time series data (15-minute or hourly) tended to suffer from large gaps in measurement. For example, temperature data at some locations would decrease in magnitude and suddenly jump in value, as illustrated in Figure 6-1. Continuous time series of temperature and DO data were available at or near the main model boundaries on the Sacramento River, the San Joaquin River and at Martinez at well as at several other locations. There were frequently large gaps in the data during the modeled period for each of these data types.

Chl-a data from continuous measurement equipment as fluorescence was deemed to be of insufficient quality to use in setting model boundary conditions or as calibration data. Jassby (2005) converted fluorescence values into chlorophyll a concentrations using linear regressions between grab sample chlorophyll a data paired with the nearest recorded fluorescence data as a method for conversion to chl-a mass units. We also analyzed fluorescence data for this project and developed regression relationships between fluorescence and chl-a data at Hood, Mossdale

[10] http://www.hec.usace.army.mil/software/hec-dss/hecdssvue-dssvue.htm

and Martinez obtained from BDAT. The model fits, shown in the Appendix Section 17.4 Figure 17-19, Figure 17-20 and Figure 17-21 respectively, were poor. Muller-Solger (2002) observed that fluorescence and corresponding chlorophyll *a* concentrations measured in grab samples were often low (Chl. *a* < 5 ug/L) and only weakly correlated with each other.

The quality of grab sample data for the nutrients was good, although it was generally only available at approximately monthly or bi-monthly intervals. However, data gathered by different agencies could have different ranges of values.

Figure 6-3 shows a comparison of Environmental Monitoring Program (EMP) and USGS measurements at Rio Vista and Point Sacramento. The original measurement of chlorophyll a was converted to algal biomass as described in Sections 5.5.2. and 5.2.4. Both agencies performed these measurements at irregular intervals, approximately monthly. The measurements are within the same range of magnitude in most months, but could also vary by factors of 2 – 5, particularly when a peak occurred. The general pattern was similar.

Figure 6-4 shows similar comparison for DO data at the same locations. The measurements generally track very closely, both in magnitude and pattern. Figure 6-5 shows NO_3+NO_2 measurements – again they track fairly closely in magnitude when taken at similar times.

The situation for PO_4 is quite different. Figure 6-6 shows the inter-agency comparison at Point Sacramento is not very good. In addition to differences in magnitude of up to a factor of four, there is no apparent similarity in pattern.

Figure 6-7 through Figure 6-9 show interagency comparison at similar locations on the lower Sacramento River below the confluence – comparing Martinez and Suisun at Bulls Head and Chipps and Pittsburg. As with the direct location comparisons, algae (Figure 6-9), DO (Figure 6-9), and NO_3+NO_2 (Figure 6-7) track closely in magnitude and pattern, while PO_4 (Figure 6-8) measurements vary widely in magnitude with no apparent pattern.

6.4 Missing data

Although boundary conditions require that data gaps be filled in some manner prior to application, data for calibration and validation required no further modification after suspect data were removed.

Several methods were used to fill gaps in time series of data. Missing data for effluent boundaries and flow boundaries presented slightly different problems and different approaches were used for each. The methodology for setting effluent boundary conditions and the time periods when effluent data were available for each constituent is covered in Section 8. The methodology for filling large data gaps in boundary condition data focused on setting values using Water Year Type as the primary criterion. The reasoning behind this is discussed in Section 10.

For continuous temperature and DO time series used to set river inflow boundary conditions at Sacramento, Vernalis and Martinez, the software package CatMV 1.1[11] was purchased to automate gap filling. The statistical methodology used in this package, Singular Spectrum Analysis (SSA), is described in Appendix Section 17.5. This method was generally used to fill short (~ 2 week) gaps for an entire year or two, and occasionally to fill longer gaps (up to 1 – 2 months). Figure 6-2 illustrates the results when gaps in water temperature for the Sacramento boundary condition were filled using the CAT-MV software.

When an entire year or a large portion of a year of data were missing for DO or temperature, a (filled) year of the same Water Year Type was used to replace the missing data. The reasoning behind this method is explained further in Section 8.8.3.

Some data gaps were filled "by hand" using data from a nearby time period (for example, when temperatures were constant), by selecting data from a time period in a different year with a similar trend and magnitude, or by using data from a near-by location. In cases where the gap was very small, linear interpolation was used to fill data gaps, although this method was rarely used with continuous measurement data. Linear interpolation was used on irregular time series when converted to regular interval data – this is the default methodology used in HEC-DSSVue for conversion to regular time series.

For meteorological data, the gaps in NOAA cloud cover data were estimated using solar radiation data (from CIMIS). For example, the gaps of cloud cover were filled using similar patterns of solar radiation. If solar radiation data were not available, the gaps of cloud cover were just estimated comparing the cloud cover just before or after the gaps. Wind speed data gaps were filled using time data from periods with similar wind magnitudes in the same season.

When data values were missing because they were below instrument detection limits, the value was set at the half the stated value of the detection limit, for both boundary condition data and for comparison in calibration data. In calibration, comparisons of model with measurements at the detection limit are a potential source of bias in the statistical measures. However, such measurements are typically within the uncertainty of the model calculations. This is discussed in Section 10.

[11] http://www.gistatgroup.com/cat/detail.html#mv

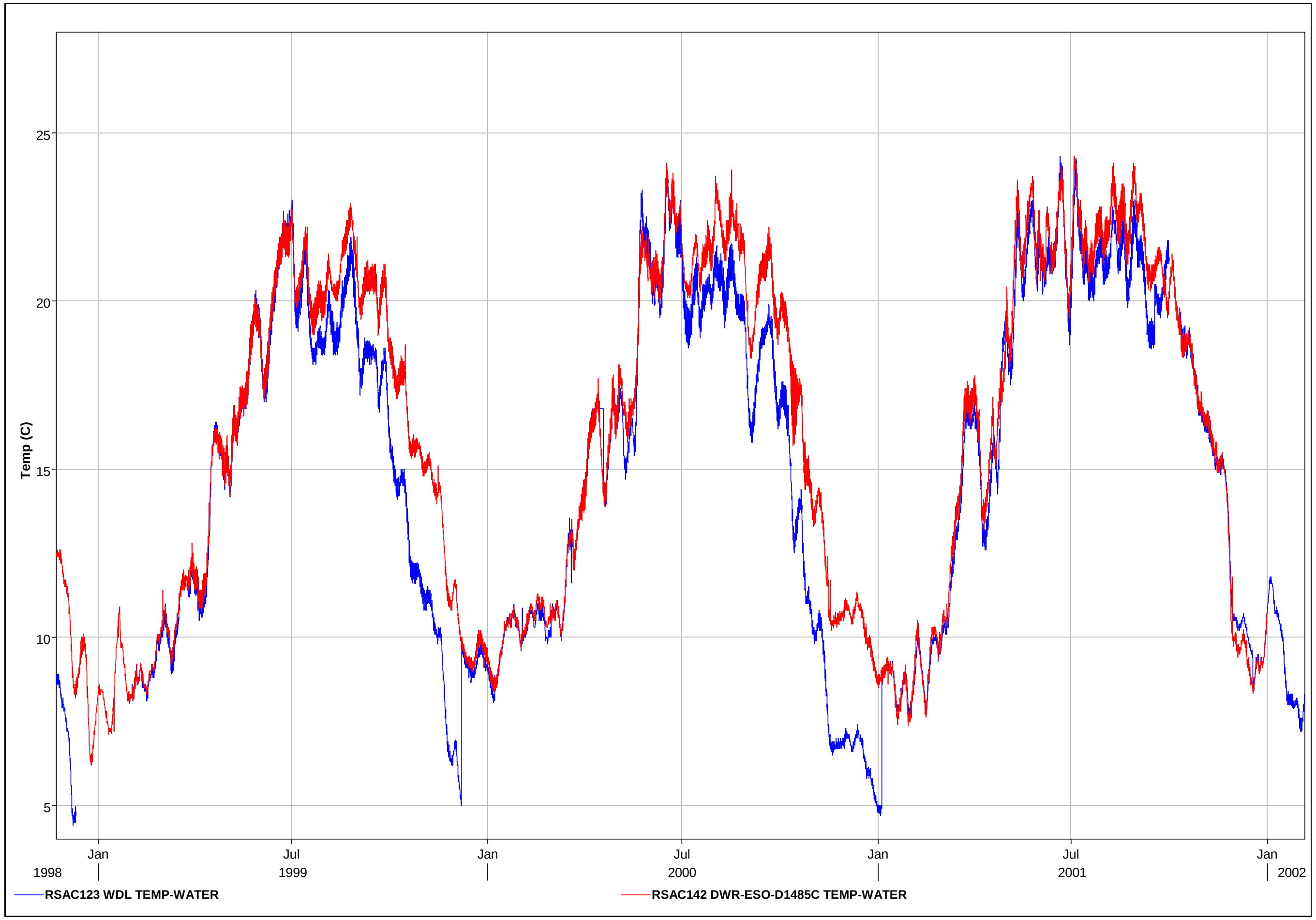


Figure 6-1 Suspect data were identified at RSAC123 (blue line) by large jumps in value at low temperatures in comparison with water temperature data at RSAC142 (red line).

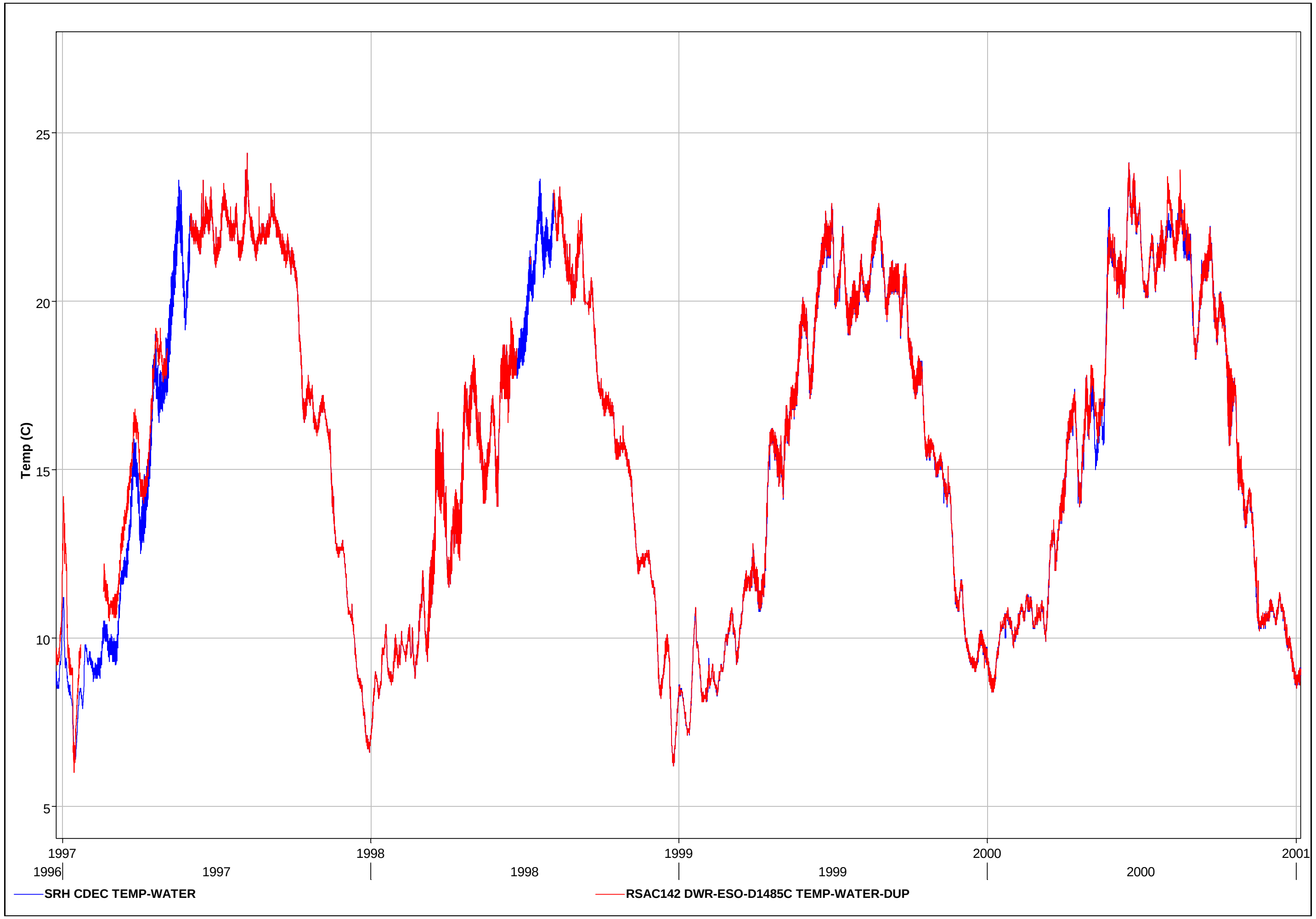
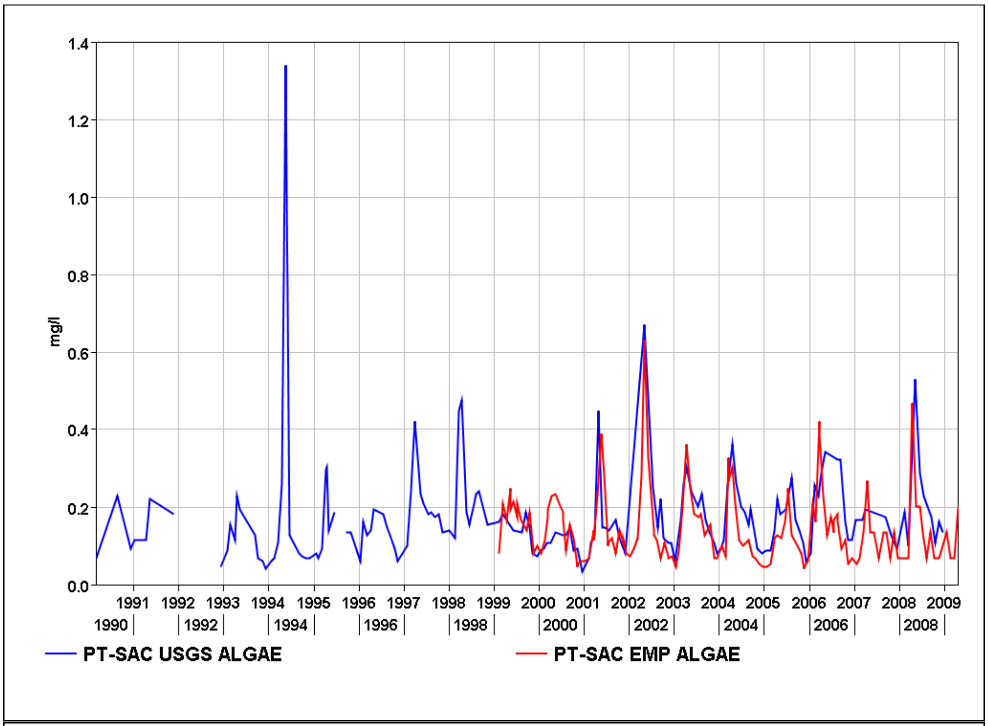


Figure 6-2 Water temperature data with gaps at Hood on the Sacramento River (red line) – fill-in data were approximated using Singular Spectrum Analysis (blue line).



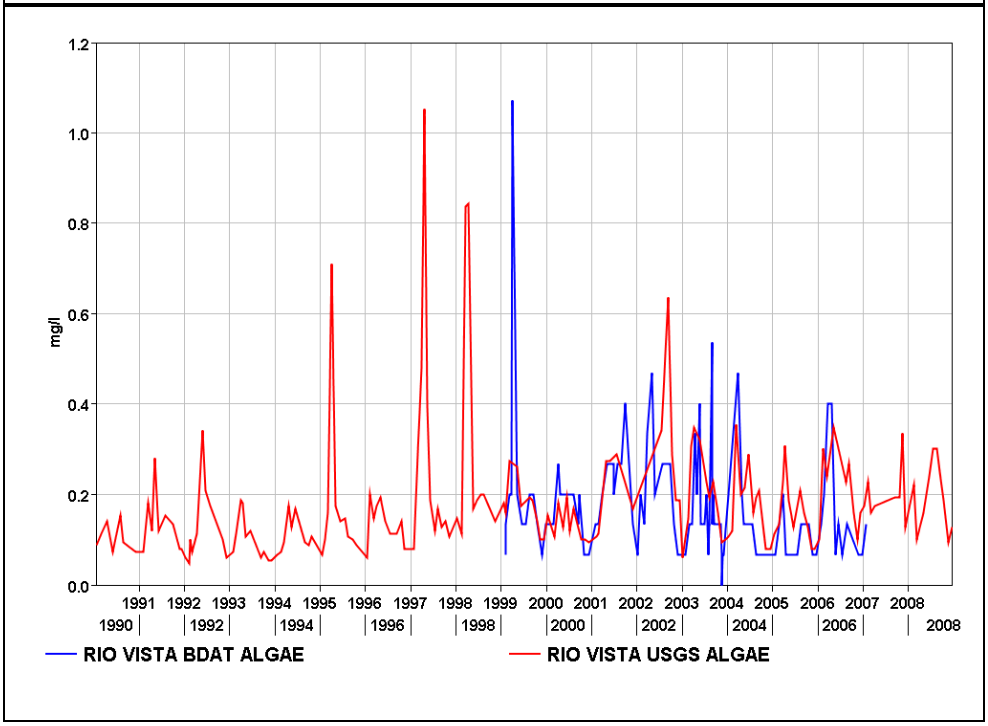


Figure 6-3 Comparison of EMP and USGS measurements at Point Sacramento (upper) Rio Vista (lower) – chlorophyll a measurements were converted to biomass of algae.

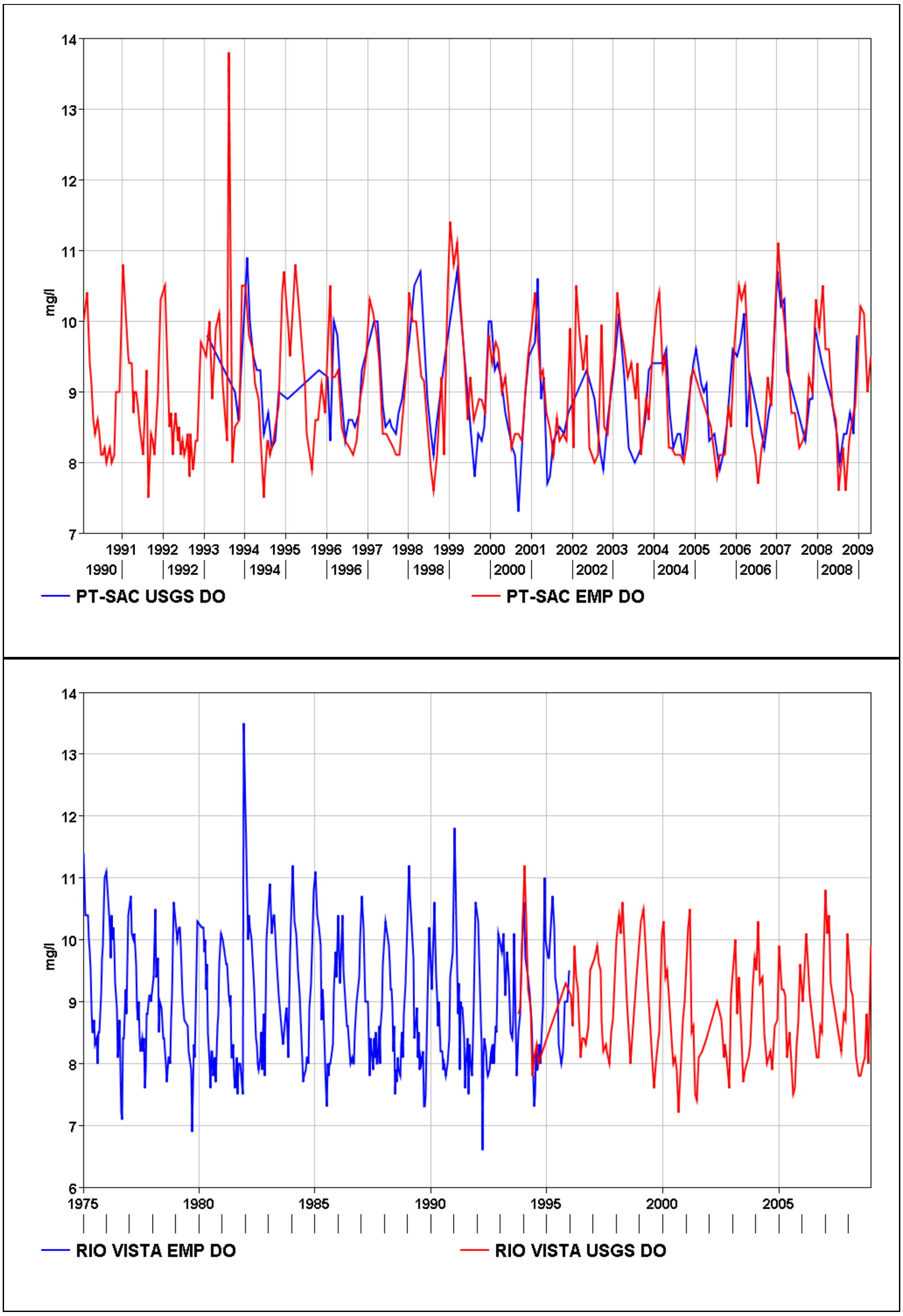


Figure 6-4 Comparison of EMP and USGS DO measurements at Point Sacramento (upper) Rio Vista (lower).

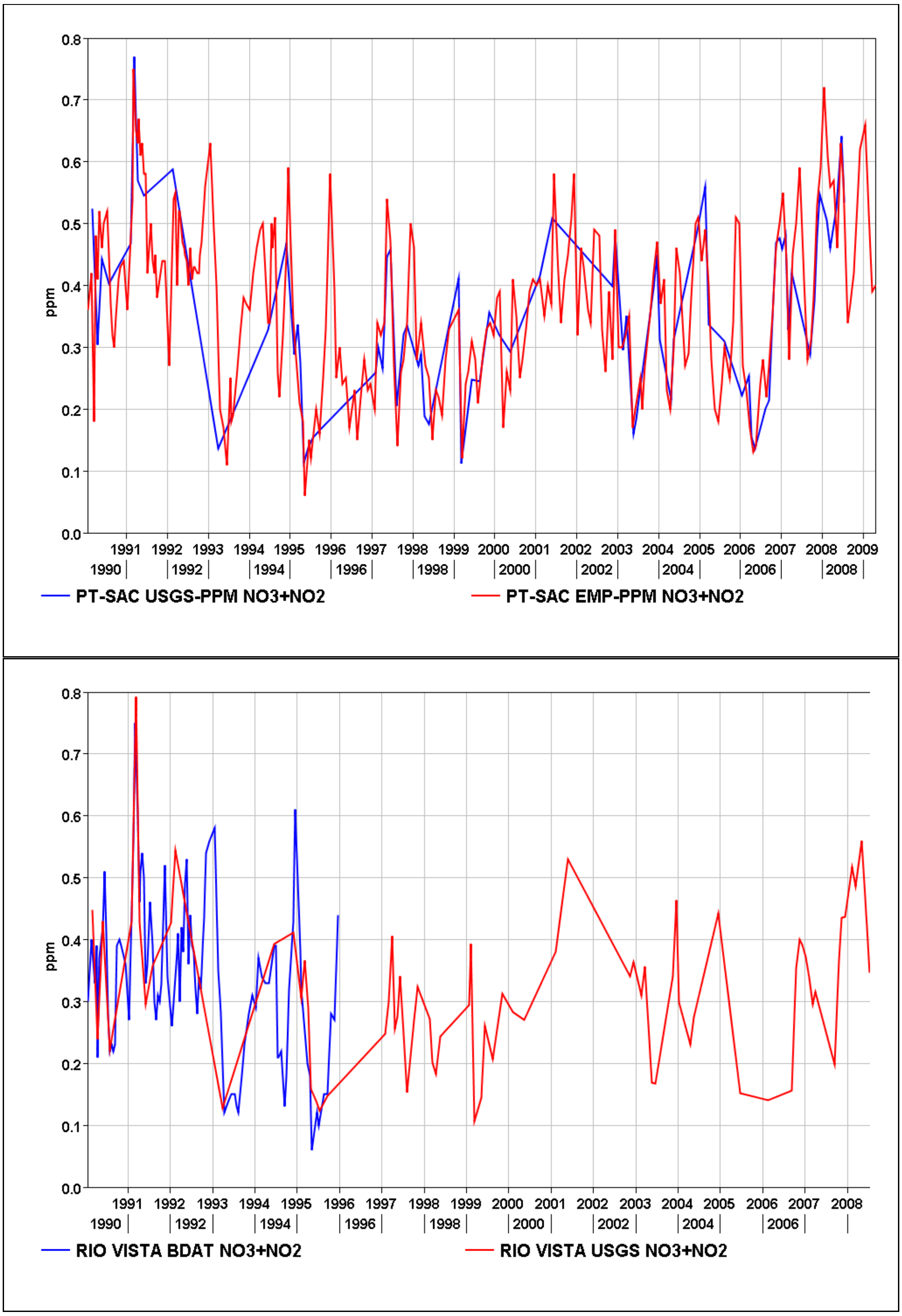


Figure 6-5 Comparison of EMP and USGS Nitrate+Nitrite measurements at Point Sacramento (upper) Rio Vista (lower).

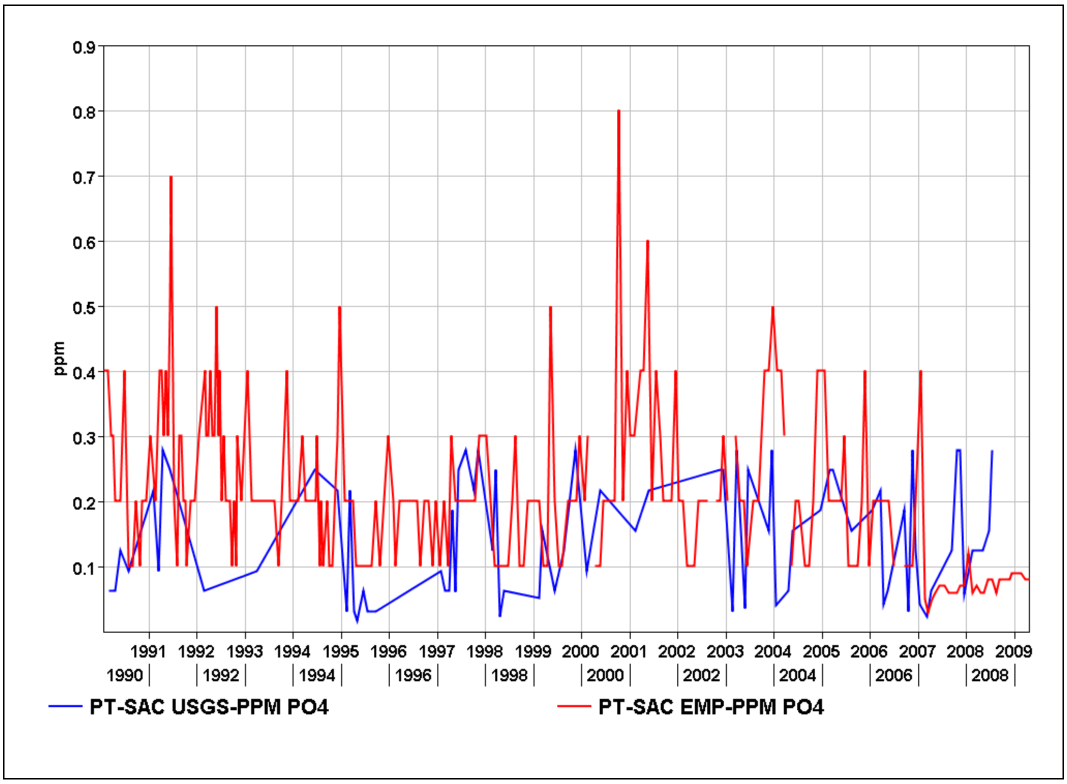


Figure 6-6 Comparison of EMP and USGS ortho-phosphate (PO_4) measurements at Point Sacramento.

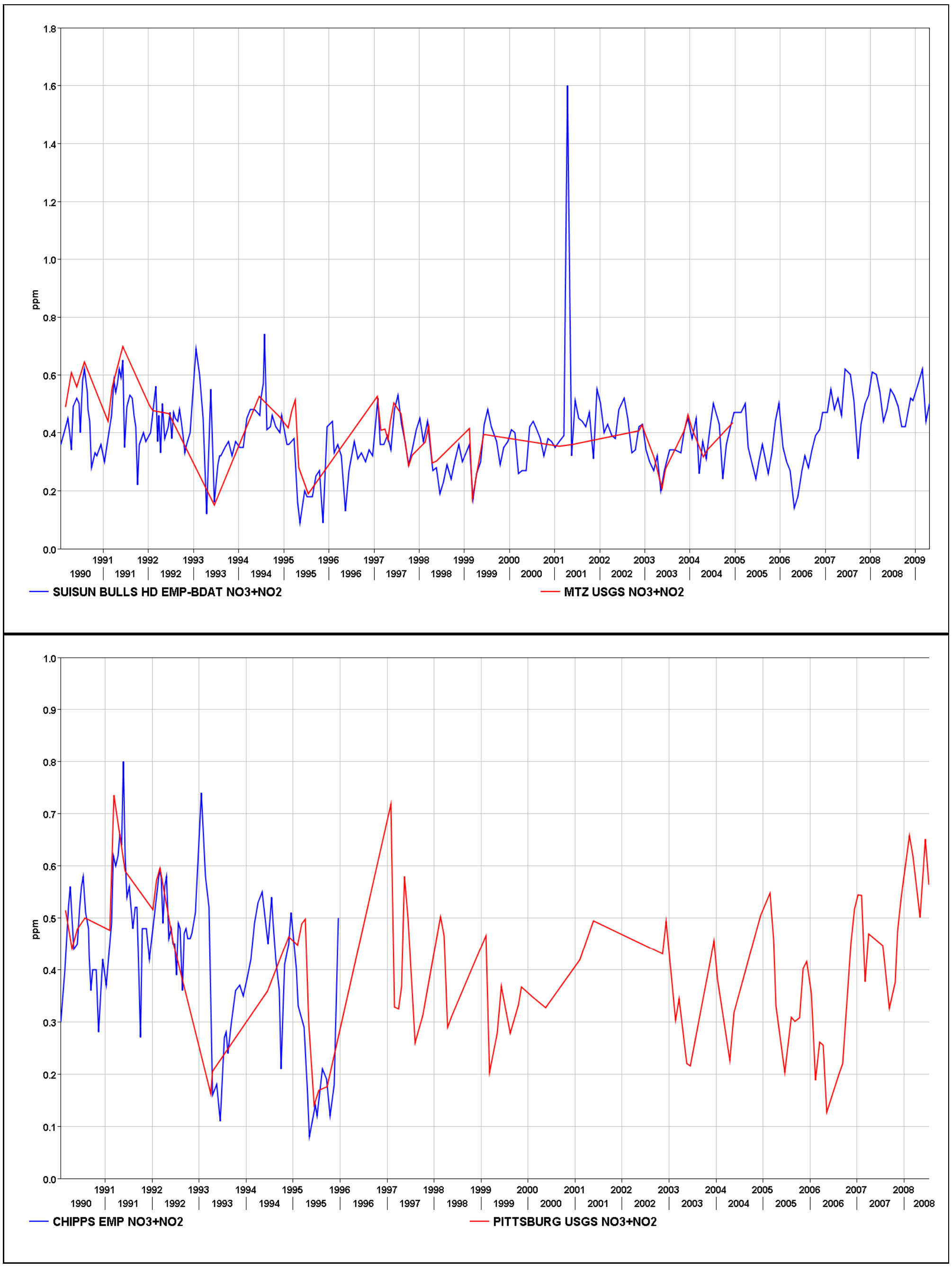


Figure 6-7 Comparison of EMP and USGS Nitrate+Nitrite measurements near Martinez (upper) and near Chipps and Pittsburg (lower).

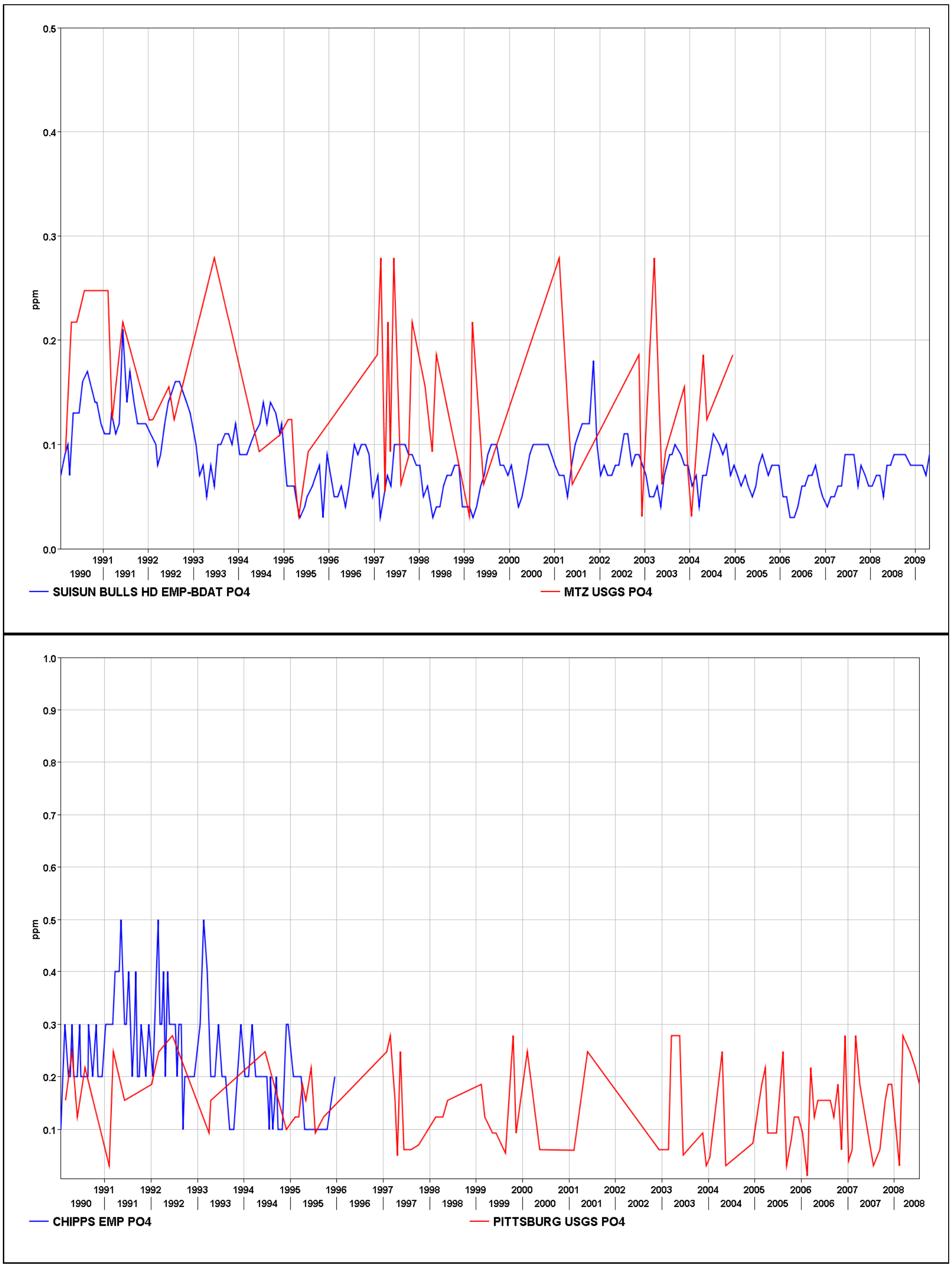


Figure 6-8 Comparison of EMP and USGS PO_4measurements near Martinez (upper) and near Chipps and Pittsburg (lower).

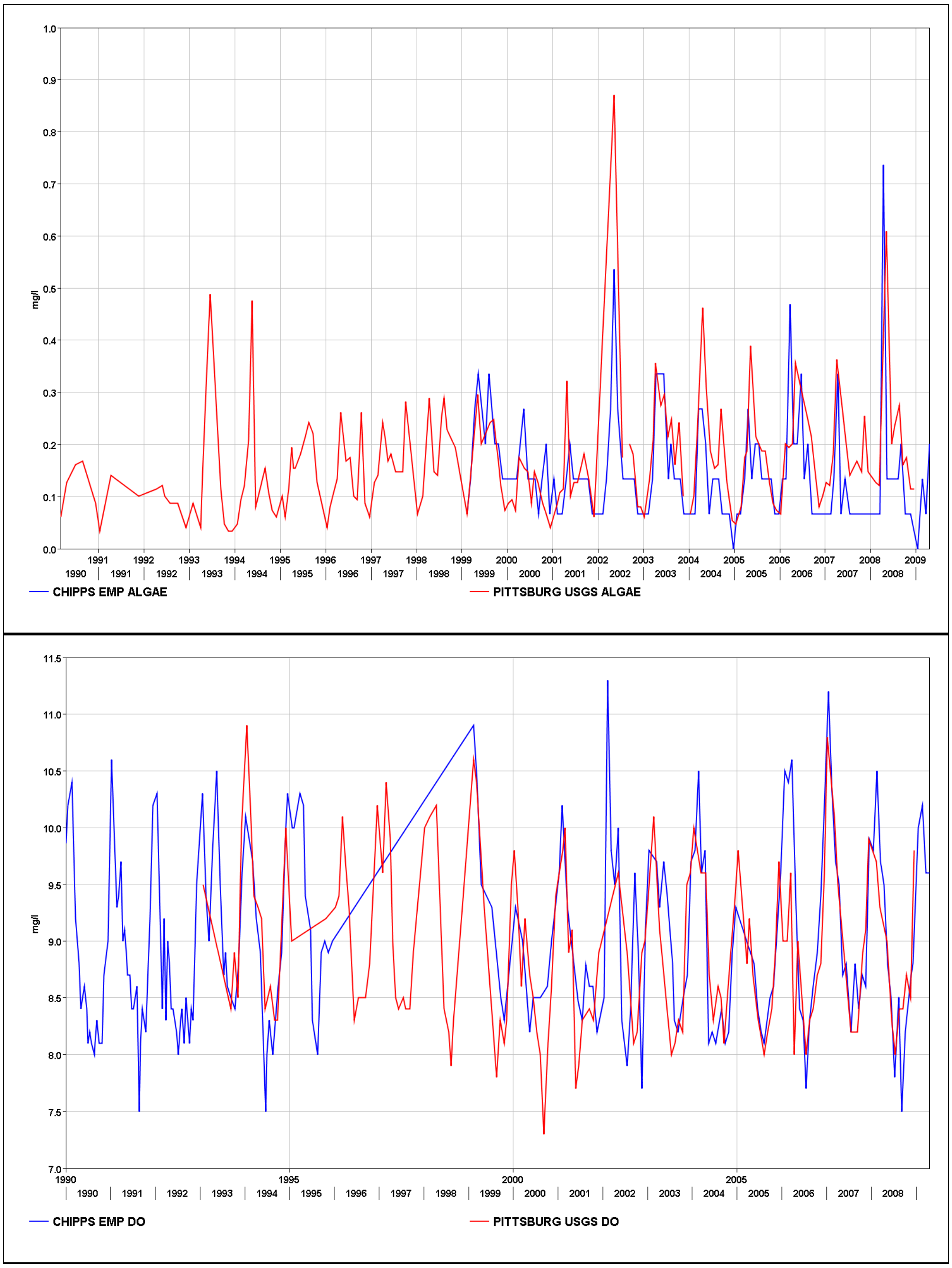


Figure 6-9 Comparison of EMP and USGS algae (upper) and DO (lower) measurements near Chipps and Pittsburg .

7 Data Availability: Time Span and Locations

Data were needed to set concentrations for each of the eleven constituents at each river boundary illustrated in Figure 4-1 at each effluent boundary shown Figure 4-2, and at the 258 DICU boundaries for the modeled time period, 1990 – 2008. In addition, data were needed for calibration and validation of the model.

No data were available to constrain modeled nutrient concentrations or to set boundary conditions in the Yolo/Cache region. Only a few measurements were available in Suisun Marsh.

7.1 USGS Data

Figure 7-1 shows the locations of water quality data, including nutrient measurements, downloaded from the USGS website. Data were available at irregular intervals and, depending on the constituent, were sparse at some locations. Figure 17-3 and Figure 17-4 illustrate the availability of nutrient data at USGS locations from 1990 – 2008 (except temperature).

Measurements, which were generally made at depth increments of one meter, include water temperature, DO, nitrite, combined nitrate+nitrite, orthophosphate, chl-a, and pH (pH was only used in an ancillary manner). Except for temperature, measurements tended to be concentrated at the 1-meter or 2-meter depth at each location. Temperature data were consistently recorded at each available depth, while nutrient data were sparse at many locations.

Nutrient data from a single depth, usually 1-meter, was used although occasionally a couple of data points from one depth below or above were used to fill in missing data. For example, chl-a data from the 2-meter depth had the greatest frequency of measurement, but occasionally a gap occurred and data at 1-meter was available and used to fill the gap. This strategy was utilized when an analysis of the measurements indicated only minor variation with depth.

Figure 7-2 and Figure 7-3 are plots of temperature with depth along the Sacramento River transect defined by the USGS station locations. Note that, the variation in temperature with depth is very small on August 15, 2006, indicating that a one-dimensional representation used in DSM2 is sufficient for modeling temperature along the Sacramento River.

7.2 U.C. Davis - R. Dahlgren and M. Johnson

R. Dahlgren from U.C Davis supplied several years of data (mid-1999 to early 2005, depending on location) comprising a complete suite of measured water quality parameters at several model boundary locations (see Figure 7-4). Measured parameters were used (see Appendix Section 17.10) to develop chemical speciation models at the Sacramento and San Joaquin River model boundaries using the modeling package EQ3/6[12] and data base. These models were used to establish a general sense of the aqueous species in solution at these important boundaries. The modeling results are discussed further in Section 9.1.

[12] EQ 3/6 is an equilibrium chemical speciation model developed by T. J. Wolery at Lawrence Livermore Laboratory ; http://www.osti.gov/bridge/servlets/purl/6451946-jmax2i/6451946.PDF

Mike Johnson supplied an Access database of water quality measurements in the Delta. The data were not utilized except to confirm data availability.

7.3 WWTP Receiving Water Measurements

An important source of long-term measurements on the San Joaquin River was the Stockton WWTP measurements for receiving waters. The locations of the measurements are shown in Figure 7-5. Grab sample measurements were taken for chl-a, nitrite, nitrate, ammonia, DO (bottom and mid-depth), organic-N and BOD-10 or BOD-5 (the frequency of the last two data types is very limited). Figure 17-5 and Figure 17-6 illustrate the availability of nutrient data measurements from Stockton's WWTP receiving waters from 1990 – 2009 (except for temperature).

Two locations of Sacramento Regional (Sac Regional) WWTP measurements for receiving waters on the Sacramento River were used, one above the effluent outfall location at Freeport Marina and another downstream of the outfall at River Mile 44 (RM-44) as shown on Figure 7-6. Some measurements were available on their website[13] at infrequent intervals from 2004 – 2008. Figure 17-7 shows the availability Sac Regional receiving water nutrient measurements. Data values obtained from the website are documented in Appendix I Section17.2, in Table 17-5 for Freeport Marina and in Table 17-6 for the RM-44 location.

The Fairfield-Suisun WWTP also had a few receiving water measurements at several locations downstream of the effluent outfall locations. These were not used.

7.4 WWTP Effluent Data

Data were obtained for the effluent flow and nutrient composition from 17 WWTPs. The approximate location of the outfalls is shown in Figure 4-2. The time periods and availability of constituents is shown in Table 17-7 and in Table 17-8. Data for Vacaville, Davis and Woodland was gathered but not yet implemented as the Liberty Island recalibration was not available at the time of calibration. Because they are located outside of the model domain, estimation of flow containing their effluent into the Yolo/Cache area needs the support of additional flow data. Benicia effluent data does not need to be considered as the outfall is downstream of the model boundary at Martinez.

The source of the data for each WWTP is listed in Table 17-1 in the Appendix.

7.5 BDAT

The data obtained from the BDAT data base was the source for most of the nutrient data for the modeled constituents, both for boundary conditions and for calibration and validation. The data

[13] http://www.srcsd.com/

were mainly grab sample measurements in the form of irregular time series at intervals of approximately one month, occasionally with gaps of years in measurement.

The most complete set of related data measurements downloaded from BDAT, or obtained directly from DWR staff, was gathered by the EMP. DWR's EMP has gathered data from several sites within the Delta on a long-term basis. Figure 17-8 through Figure 17-14 illustrate the data availability of EMP and BDAT measurements from various sources (except for temperature).

Nutrient data were available at the Martinez boundary for all of the constituents except organic-P. A combination of data from BDAT and data from the USGS database was used. At the San Joaquin River boundary at Vernalis, nutrient data were available either at Vernalis or 25 km downstream of Vernalis at Mossdale. For each constituent except organic-P, data were obtained from BDAT at Hood, Greens Landing, and occasionally from points further south to develop concentrations at this boundary.

Table 17-2 through Table 17-4 in the Appendix gives the entire list of data locations found in BDAT. At some of these locations, data consisted of a few data points, so these data were not used. Some locations were very close, so data could be considered to be from the same measurement location.

Figure 17-15 through Figure 17-17 show the location of chl-a measurements. Measurements for nitrate+nitrite, ammonia, DO, orthophosphate and organic-N were generally also found at these locations.

7.6 Other Sources

An Access database of water quality measurements was developed for the Central valley Drinking Water study to characterize drinking water quality within the jurisdiction of the Central Valley Regional Water Quality Control Board. The data set ended in 2004, but included NPDES measurements at locations within and just outside the Delta. Storm water data were included nut not used.

Data from upstream locations on the Sacramento River from the data base Municipal Water Quality Investigations branch of DWR. NH_3, NO_3, NO_3+NO_2 and PO_4 data were obtained at Freeport. This data is discussed further in Section 8.8.4 in a discussion of setting boundary conditions at the Sacramento River boundary.

7.7 Data Availability by Category

7.7.1 Meteorological Data

The original nutrient model developed to investigate DO problems on the San Joaquin River near Stockton used meteorological data measured at the Stockton airport by NOAA. Two issues were identified with the use of this original data set for the current modeling effort. The first issue is that data for each of the required inputs was not available from NOAA at this location prior to 1996. In addition, in the process of calibrating the temperature model, it was found that there was sufficient variability in meteorological conditions across the Delta to render the single Stockton dataset ineffective in modeling water temperature across the entire Delta. CIMIS data were collected to supplement the original NOAA data set.

Table 7-1 shows a comparison in measurement methodology for the NOAA and CIMIS data measurements.

Figure 17-25 shows the locations of the Stockton and CIMIS meteorological measurement data reviewed for this report. NOAA Stockton meteorological measurements were used for the entire period except for wind and wet bulb measurements which were only available from 1996 to 2008. CIMIS Brentwood wind speed measurements were used for the early period 1990 - 1995 as measurements were available for the entire time period. Wet bulb was not available before 1996, and was instead calculated (see Appendix I Section17.7).

7.7.2 Water Temperature Data

Water temperature data were generally available as regular time series at hourly intervals, or occasionally at 15-minute intervals. Much of the temperature data were obtained from the DWR Water Data library, or from the IEP and CDEC databases. The data were of mixed quality, although data quality and availability generally improved after 2000. Figure 17-26 shows the locations where water temperature data were available in the Delta. Figure 17-27 and Figure 17-28 indicate the time periods and quality of data available. Discussion of the years selected for calibration and validation is covered in detail in Section 10.2.

7.7.3 DO Data

DO is the only nutrient for which continuous time series were available, and they were downloaded from the IEP and CDEC data bases. Continuous DO data were generally sparse and noisy with large data gaps. DO measurements in the interior of the Delta were available as regular time series at five locations (Rio Vista, RSAC075, RSAN007, RSAN058 and RSAN061) and as irregular time series from the USGS and BDAT databases and from the Stockton WWTP receiving water data.

Some USGS measurements were used to help constrain boundary conditions, but they were mainly used in model calibration and validation.

7.7.4 DICU Data

DICU nutrient data were set as constant values in the previous DO-models (Rajbhandari 1995a, 2000, 2001, 2003). Additional data were obtained from MWQI staff. The data were not taken at outfalls into the Delta and it was generally spare and from the early years of the model, and so was deemed of marginal value given the large effort it would take to collate the data.

7.7.5 Chlorophyll a (Chl-a)

As mentioned in Section 6.6.3, Chl-a measurements derived from continuous measurement equipment as fluorescence was deemed to be of insufficient quality to use in setting model boundary conditions or as calibration data. Grab sample measurements were used exclusively for chl-a.

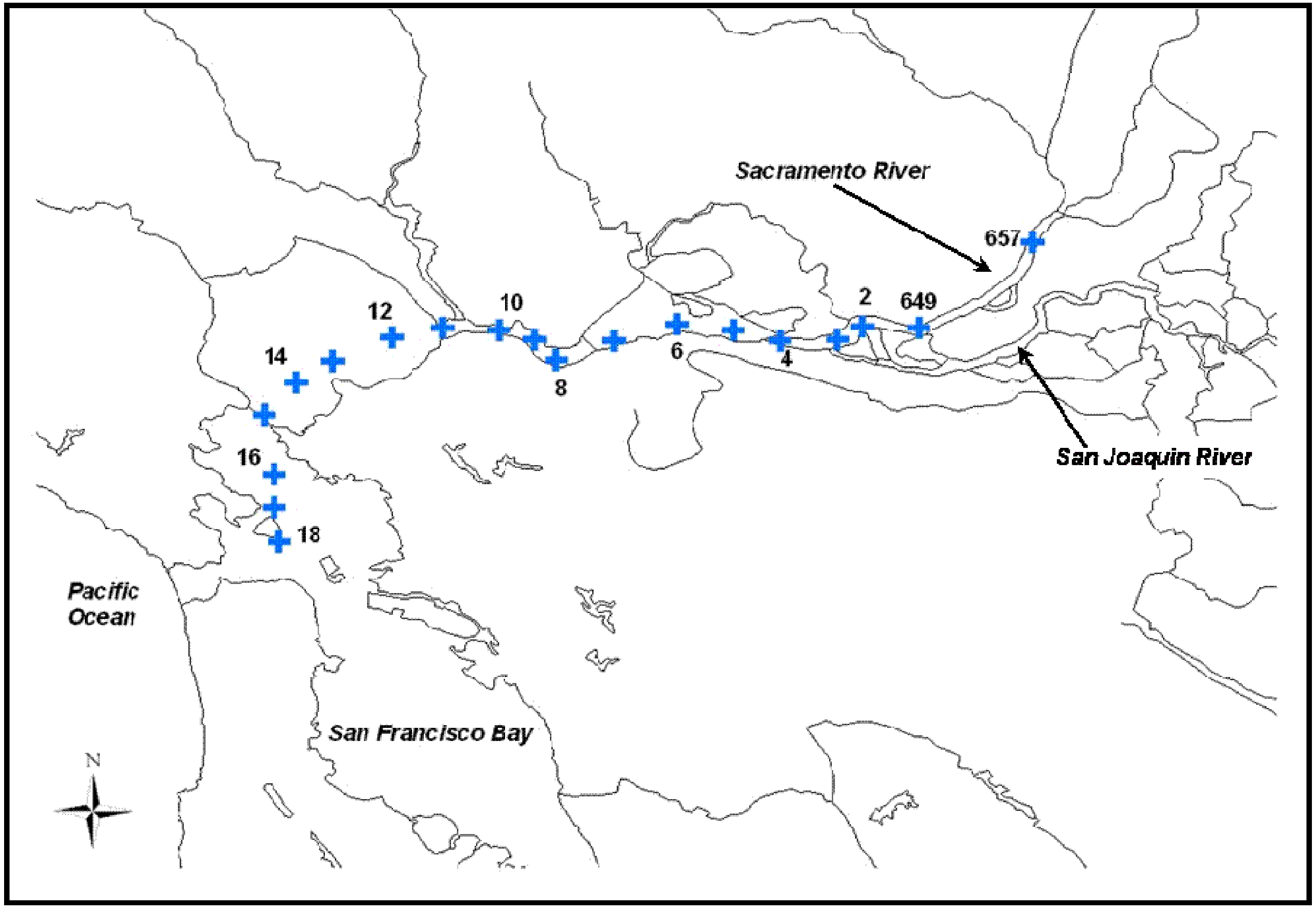


Figure 7-1 USGS nutrient and other water quality parameters measurements (blue crosses) were utilized from location 8 downstream from Martinez to location 657 at Rio Vista.

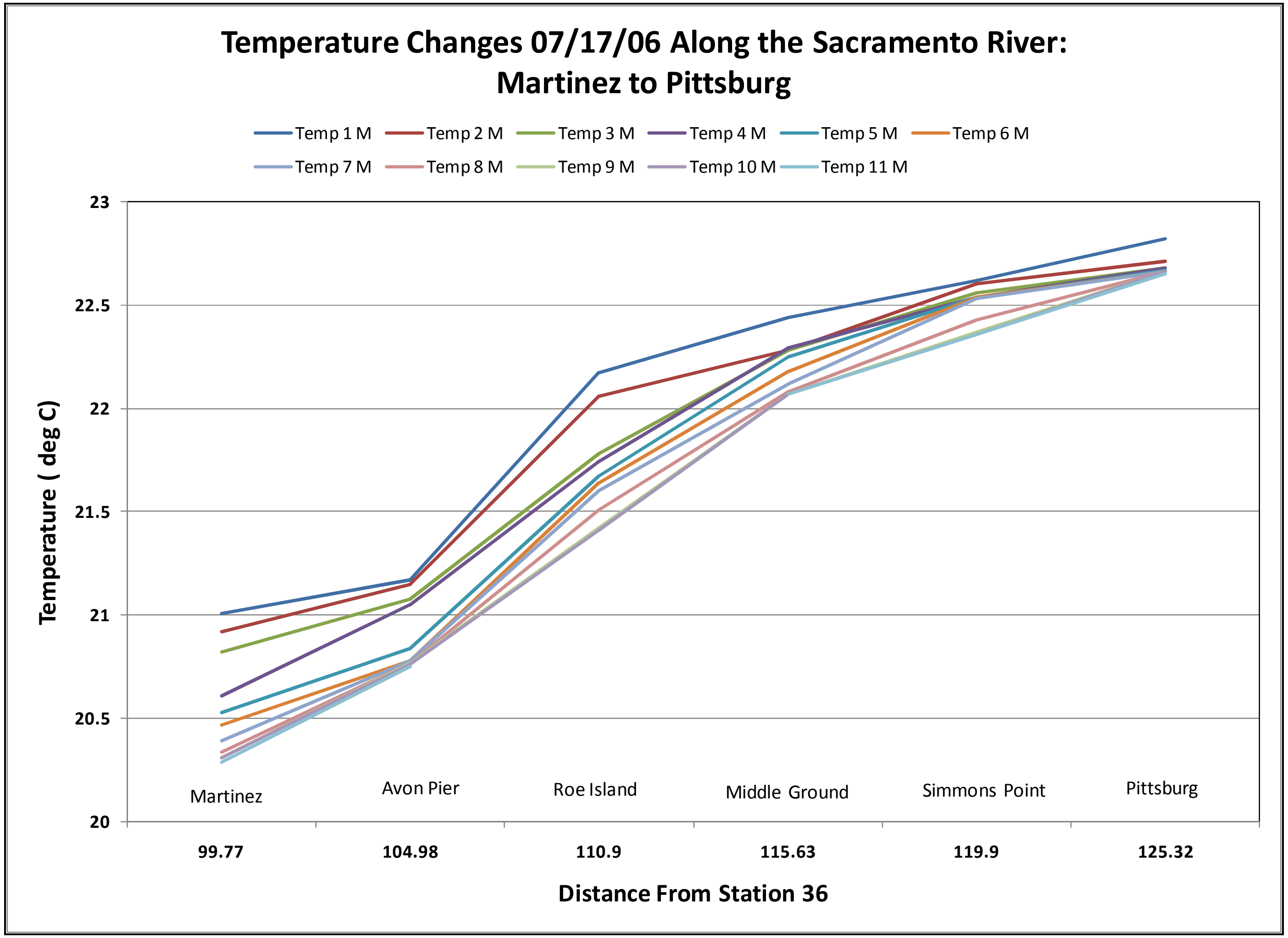


Figure 7-2 USGS temperature data at various depths from Martinez to Pittsburg on July 07.2006

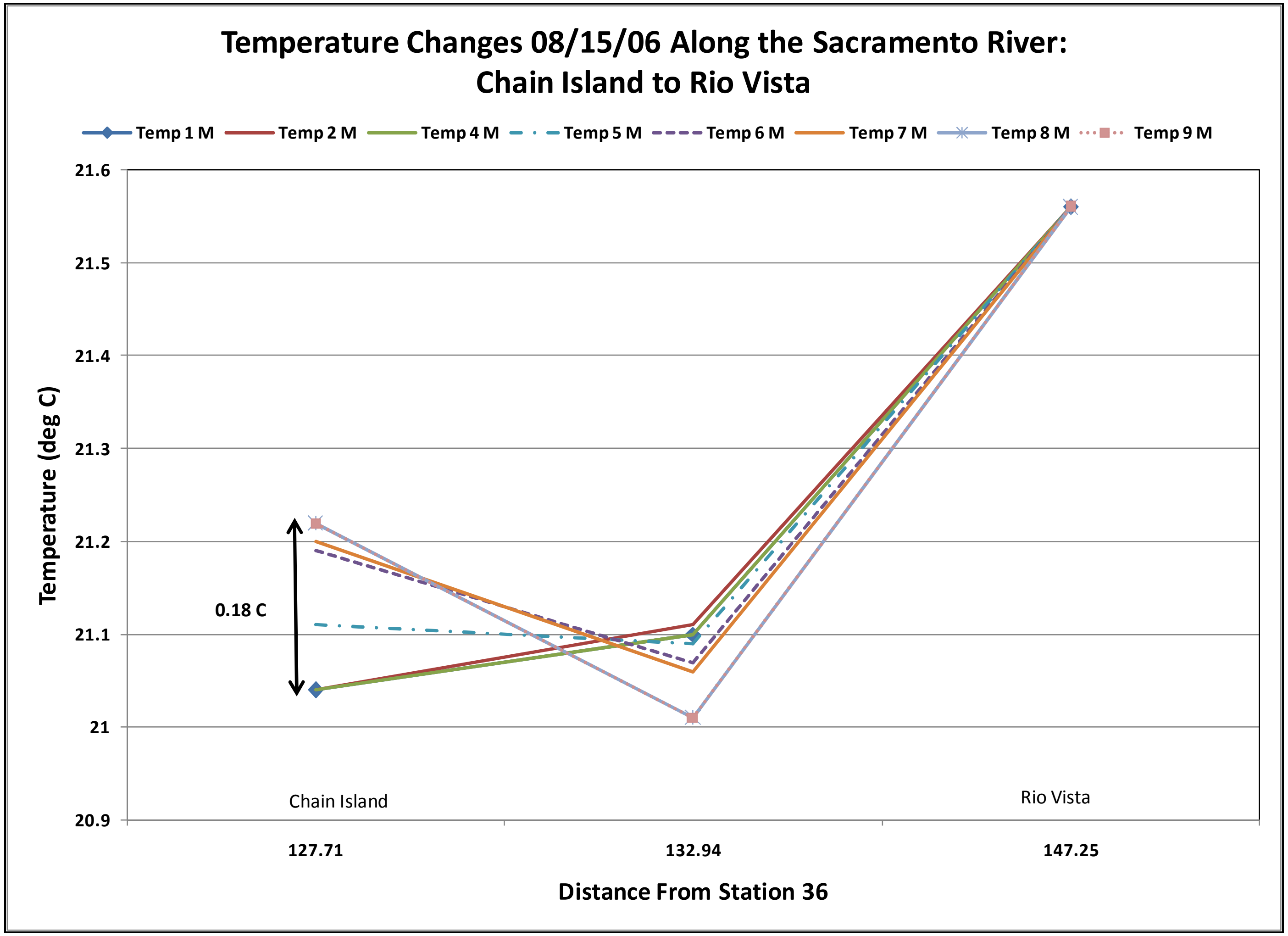


Figure 7-3 USGS temperature data at various depths from Chain Island to Rio Vista on August 15, 2006.

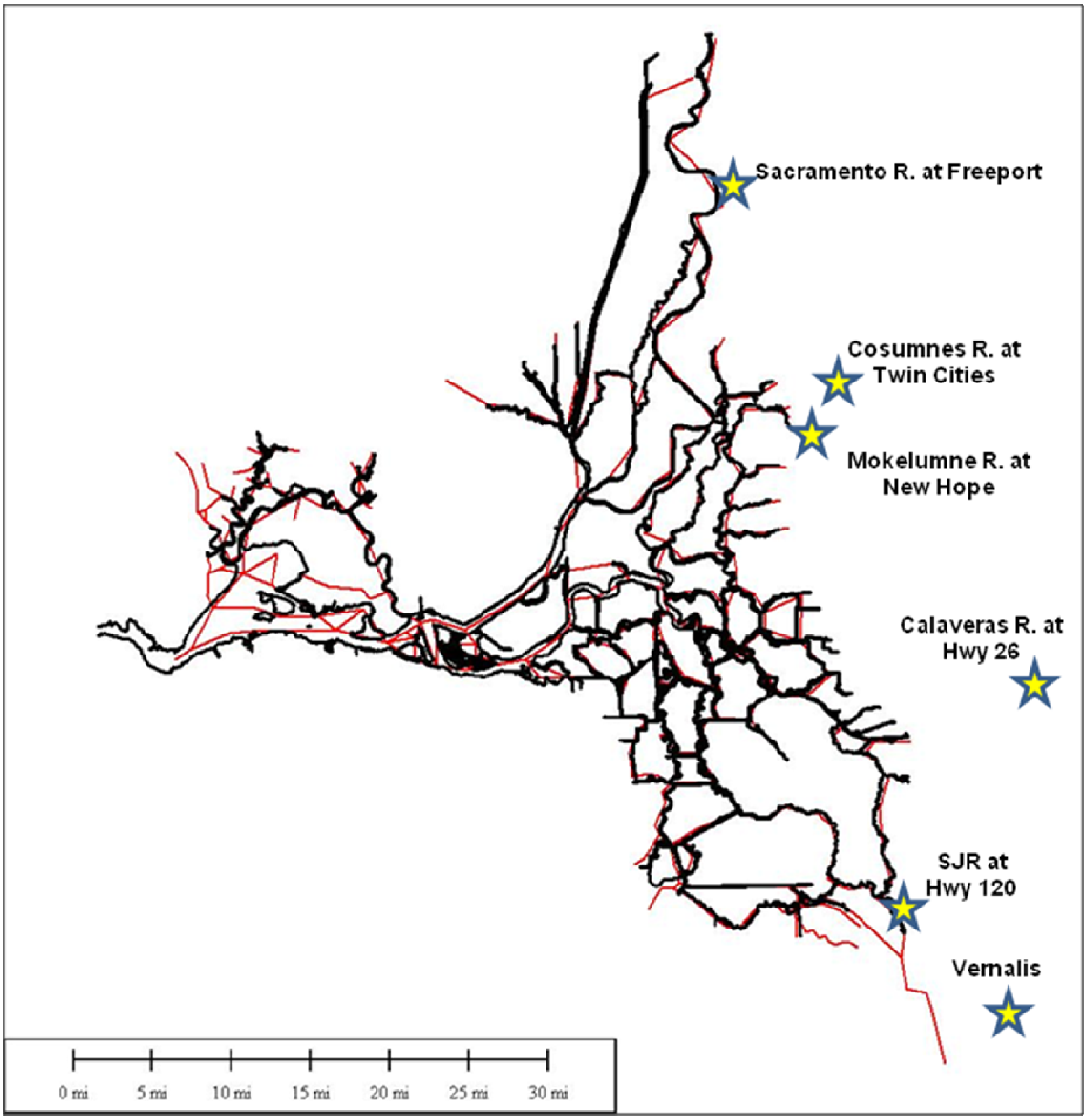


Figure 7-4 Approximate location of data (indicated by yellow stars) in Dahlgren's (UC Davis) data set used to help define nutrient boundary conditions.

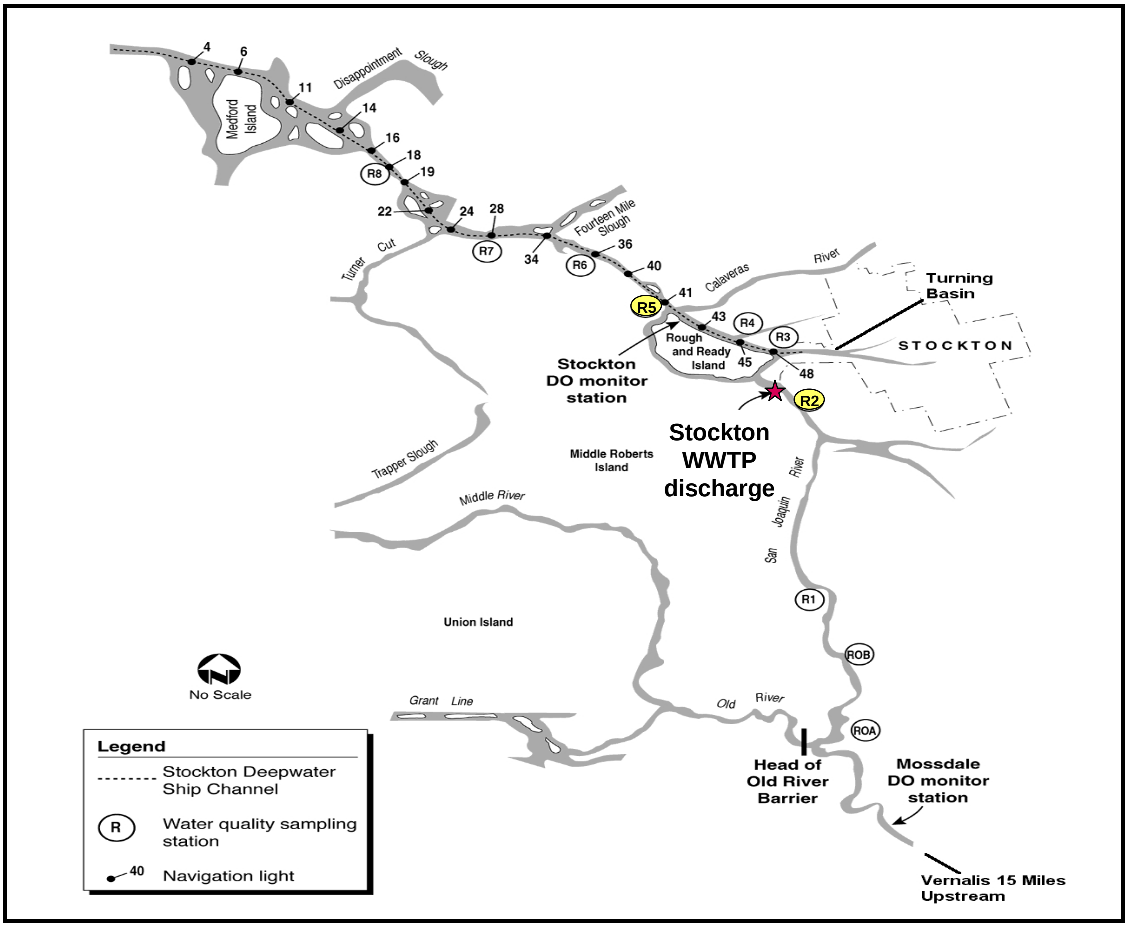


Figure 7-5 Location of the Stockton WWTP receiving water measurement locations (Figure from Kendell personal communication).

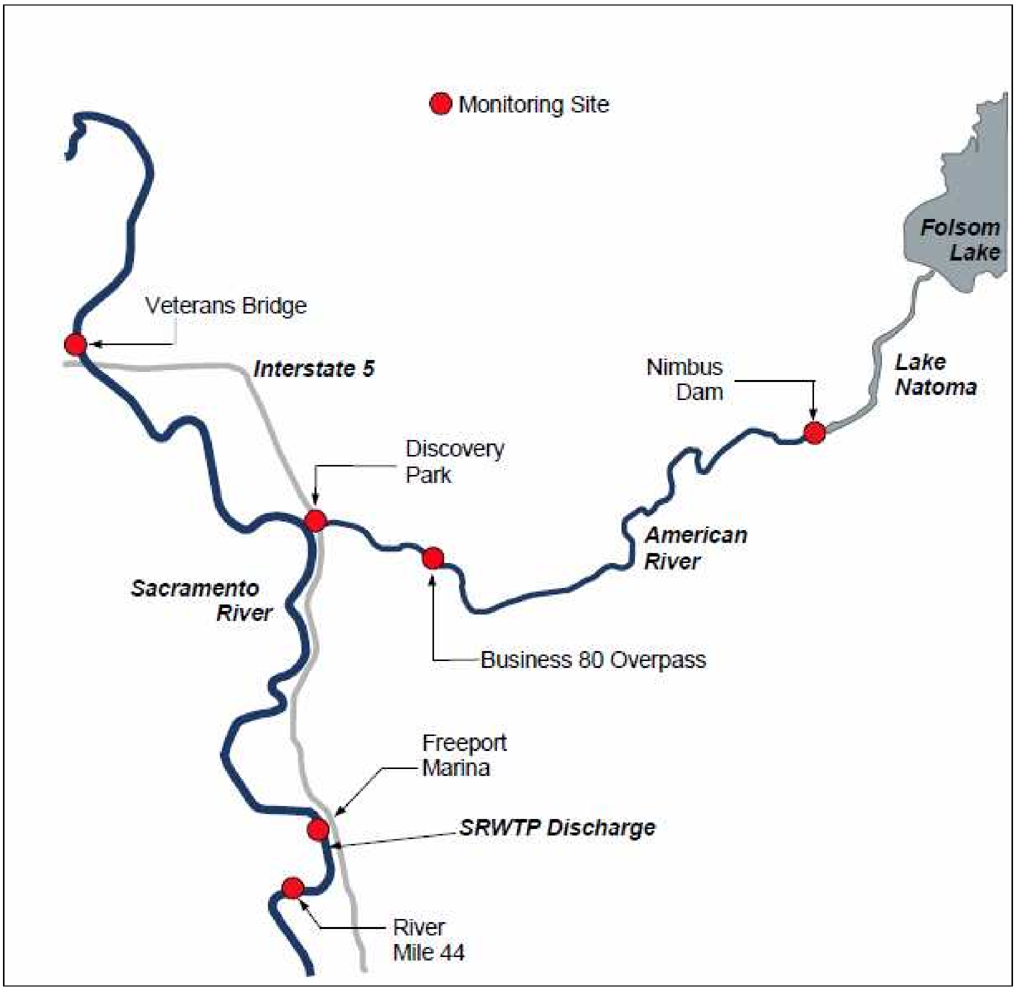


Figure 7-6 Location of the two Sacramento Regional WWTP receiving water measurements used in this report – Freeport Marina and at River Mile 44.

Table 7-1 Meteorological data – the difference between CIMIS and NOAA measurements, such as measurement height above ground, timing (instantaneous vs. average).

	CIMIS	NOAA
Measure height	2 m	10 m
Frequency	Hourly/Daily averaged	Hourly
Constituents	Solar Radiation Air Temperature Soil Temperature Dew Point Relative Humidity Wind Speed Wind Direction Wind Gust Vapor Pressure Precipitation Evapotranspiration	Sky Condition Visibility Weather Type Dry Bulb Wet Bulb Dew Point Relative Humidity Wind Speed Wind Direction Value For Wind Character Station Pressure Pressure Tendency Pressure Change Sea Level Pressure Hourly Precipitation Altimeter
Stations in Delta	Brentwood (Jan98 - Dec05) Concord (Apr01 - present) Hasting Tract (Jan98 - present) Lodi (Jan98 - Dec00) Lodi West (Sep00 - present) Manteca (Jan98 - present) Tracy (Sep01 - present) Twitchell Island (Jan98 - present)	Stockton (88-present)

8 Setting Boundary Conditions

Figure 4-1 shows the locations of the standard Historical model boundaries and Figure 4-2 shows the locations of the effluent boundaries. The values used to set boundary conditions were dictated by the availability and quality of data, and also on a practical limitation in QUAL. QUAL has a limit on the number of time-varying variables (15MIN, 1HOUR, 1DAY) that can be used in any simulation, so some boundaries were set at monthly intervals (i.e., as constant over each month) or as a constant even if time-varying data were available more frequently during part of the application period. Depending on the sensitivity of the model calculations to changes in the concentration of a constituent, a constant concentration boundary was sometimes deemed reasonable even when other data were available. In some cases, modification of the data were needed for constituent input values at inflow boundaries when data were not available directly at the boundary location.

A number of the effluent sources of interest for ammonia and the other nutrients lie within the Suisun Bay and the Carquinez Strait (Figure 4-2). In QUAL, outgoing tides transport water quality constituents from these sources down past the Martinez boundary and out of the model domain. In the physical system, these constituents would flow back into areas upstream of Martinez on incoming tides, but in QUAL the computation results in a loss of mass at the Martinez boundary which has the potential to significantly alter modeled nutrient concentrations and thus nutrient dynamics upstream of this boundary. Because this area is of significant importance to the Delta ecosystem, an estimate was calculated of the magnitude of this loss. In addition, the potential exists to alter the Martinez boundary conditions in subsequent model runs to reintroduce this mass on incoming tides. The consequences of this observation are discussed in detail in Appendix Section 17.11.

8.1 Flow and salinity

Except for effluent boundaries and the three exceptions noted below, boundary conditions for HYDRO and concentrations of salinity (as EC) in QUAL were accepted as presented in DWR's Historical model.

Small problems identified in the Martinez stage boundary in 2007 and 2008 were corrected, and updated data on diversions and exports to Contra Costa Water District was implemented for 2008.

Inflow data for the "Lisbon Toe Drain" in the Yolo Bypass region (CDEC symbol "LIS") was implemented for several years (approximately 2004 – 2008). During periods where the DSM2 flow boundary condition for the Yolo was above 2,000 cfs and the Lisbon Toe Drain flows were also above 2,000 cfs, the value of the Lisbon Toe Drain flows was subtracted from the Yolo boundary. As shown in Figure 17-29, the Yolo flows used in DSM2 are only positive at the same time as Lisbon Toe Drain flows (Lis in the Figure) when Lisbon Toe Drain flow exceeds 2,000 cfs. At this value, it is reasonable to assume that they were already included in Yolo Bypass flow estimates in DSM2. Note that the USGS only reports Yolo flows (at their Woodland station) above 1000 cfs.

8.2 Meteorology

Meteorological data is set at hourly intervals in the model. As mentioned previously, several problems were identified in the application of meteorological data, the most important being the inability to apply regional variation in meteorological boundary conditions (i.e., all meteorology is applied globally). In addition, no single location (shown in Figure 17-25) had a complete data set of boundary condition for the entire modeled period, 1990 – 2008.

A model sensitivity analysis on meteorological boundary conditions showed that modeled water temperature was most sensitive to the value set for wind speed, so considerable effort was taken to set wind boundary conditions. Figure 17-30 and Figure 17-31 show that there can be a factor of two variation in wind speed, either at different locations from the same measurement agency (CIMIS) or from different measuring agencies, NOAA vs. CIMIS, respectively, even though the measurement locations are in close proximity.

Initial model calculations for water temperature were used to identify preliminary meteorological regions, *i.e.*, regions in which a single set of meteorological conditions would apply. Two main regions were identified, as shown in Figure 8-1. The South Delta region was reasonably well-calibrated using the existing Stockton data set (see Figure 8-2), but in the North Delta region modeled summer water temperature was high except in very wet water years (see Figure 8-3). In these figures, calculations from a model run with the existing wind speed at Stockton and one with a higher wind speed (factor of 1.5) are compared with data (blue line). At RSAN058 in the South Delta region, water temperature is modeled very well using the existing wind data, while water temperature at RSAC081, Collinsville, is approximated better using the higher wind speed.

Final wind speeds were set using NOAA data for the Stockton location 1996 - 2008 and the CIMIS data at Brentwood as they were available for this location 1990 - 1995. Brentwood values were initially too high, so they were decreased by a factor of 0.85 to more closely match average Stockton values. During summer, the values for wind speed were increased by a factor of two from April through October, with a three-day linear ramp-up and ramp-down. Cloud cover, atmospheric pressure, and air temperature (dry bulb) were also set using NOAA data at Stockton. Prior to 1996, wet bulb measurements were also sourced from NOAA data.

Because wet bulb measurements were not available at any station prior to 1996, they were calculated using measurements of relative humidity, air temperature and dew point available at Brentwood, Lodi and Manteca (see Appendix I Section 17.7 for a description of the method).

Calculations during the water temperature calibration process uncovered convergence problems when inflow and inflow temperature were both low. In two time periods (portions of 1990 and 1991), the model could not converge to a solution. Analysis of the problem revealed that when the diurnal variations in wet bulb and dry bulb temperatures were too extreme, the model would not converge. The problem was alleviated by smoothing wet bulb and dry bulb temperatures during those time periods. The resulting boundary conditions are illustrated in Figure 17-32.

8.3 Water Temperature

Boundary conditions for water temperature needed to be set at each boundary shown in Figure 4-1. Daily or hourly time series data were available through the IEP and CDEC data bases for many of the modeled years at or near the boundaries for the Sacramento and San Joaquin Rivers, and at Martinez. Missing data were filled as described in Section 6.4, and when entire years were missing they were filled using data from the same Water Year Type at that location (or nearby location, depending on availability).

Boundary inflow temperatures prepared for the Sacramento boundary were used at the Mokelumne and Cosumnes River boundaries. Water temperature at the Sacramento boundary was set in large part using data at downstream locations from the actual model boundary – at Sacramento River RKI location 123 (RSAC123) and at measurement location in Steamboat Slough. Initial temperature model simulations showed that the resulting temperature at Freeport was high by approximate 2°C when these data sets were used. To correct this, the Sacramento River boundary water temperature at Sacramento was decreased by 2°C from 2004 – 2008, the period where downstream measurements were use to fill the gap.

The San Joaquin River temperature boundary (RSAN112) was used both at Vernalis and at the Calaveras River boundary. Water temperature was mainly available at Mossdale (RSAN087). Examination of initial model results showed there was a small shift in time for measured versus modeled water temperature at Mossdale due to travel time from Mossdale to Vernalis. The Mossdale time series was shifted back two hours to account for this difference at the Vernalis boundary. The timing mismatch was not uniformly two hours, but that shift gave a good approximation overall.

The Yolo water temperature boundary was set at a constant temperature of 9°C as the Yolo flows mainly occur during winter and early spring when water temperatures are generally low. Water temperature for the Lisbon Toe Drain was synthesized, and set at 18.5°C from May to October, and at 11.25°C the rest of the year. The Lisbon Toe Drain may have outflow during a longer portion of the year than the Yolo.

Martinez water temperature boundary condition was only used at that boundary.

DICU flow temperature was set at a constant 9°C , which is the same value used for previous DO models in the San Joaquin River area (Rajbhandari, 2003).

8.4 Nutrients – Delta Boundaries

Where possible the nutrient model boundaries were set using EMP data. EMP nutrient data were available at approximately bi-monthly intervals. The reasoning behind this decision is:

- EMP is well-documented (methods and locations)
- it is internally consistent (collected by the same agency over many years)
- it covers the modeled time span.

EMP data downloaded from the BDAT website was processed to yield a regular time series, typically monthly, from the irregular time series data as follows. Replicate values on any day were averaged, and then loaded into HECDSS-Vue which was used to convert the irregular time series into regular daily or monthly time series. The irregular time series generally had at least monthly data values, and many times measurements were bi-monthly.

Model boundaries do not necessarily coincide with data availability. This occurs at each of the main boundaries (the Sacramento and San Joaquin Rivers, and at Martinez). The methodology adopted for these boundaries was to transform nearby "good" data to upstream or downstream model boundary conditions. For example, if measurements were not available at the Sacramento or San Joaquin River inflow boundaries, modification to the substitute data were needed either to account for travel time from the inflow location to the measurement point or for changes in concentration between the model boundary and the first available measurement location. For example, since nutrient data were available at Greene's Landing (RSAC139) and at Hood (RSAC142) for setting boundary conditions, changes in the boundary value of concentration or temperature needed to be made to account for the dynamics that occurred between these two points and the model boundary.

There was no data available directly at the northern boundary of the DSM2 model (north of Freeport). There was data at the Freeport node in the model, south of northern-most node in the model domain, and at the downstream locations at Greens Landing and Hood. Freeport is also known by its "RKI", or River Kilometer Index, as RSAC155 (located 155 km from the Golden Gate). Several strategies were used to set boundary conditions here.

At the San Joaquin River boundary at Vernalis, nutrient data were available either at Vernalis or 25 km downstream of Vernalis at Mossdale. When Mossdale data were used, a minor modification was occasionally necessary to account for travel time or small changes in concentration as it was for the Sacramento River boundary. DWR's Environmental Monitoring

Program (EMP) data were used to set boundary conditions at Vernalis for chl-a, NO_3, NH_3 (total ammonia), organic-N, and PO_4.

At the Martinez boundary, setting nutrient boundary values was relatively straightforward as sufficient data were available through BDAT. For some constituents, USGS data were available at nearby locations for comparison.

8.4.1 Ammonia

8.4.1.1 Sacramento River NH3 Boundary Condition

There was a moderate amount of NH_3 data available at Freeport, above the Sacramento Regional effluent outfall. Variability is high in these measurements as shown in Figure 17-33, and they were very sparse. The nearest downstream locations, at Hood and Greens Landing, had much higher NH_3 concentrations as they are downstream of the Sac Regional effluent outfall.

Model sensitivity runs on the Sacramento River NH_3 (and NO_3) boundary conditions showed that Greens Landing and Hood measurements (from BDAT) could be used to set the concentration at this boundary if reduced by a suitable factor. Figure 17-34 illustrates the difference between data values and the Sacramento boundary set at 0.4 times the (merged) data from Greenes Landing and Hood. This boundary condition produced suitable model results at all locations within the model, but the average value for NH_3 at the boundary is higher than measurement values for a substantial portion of the modeled period.

Because of these factors, mixing calculations using a combination of flow data and NH_3 data for the Sacramento River, Sac Regional and at Greens Landing and Hood data were used to set ammonia at the model boundary (well upstream of Freeport).

A detailed discussion on this important boundary condition is found in Appendix I in Section 17.8.

8.4.1.2 Other NH_3 Boundary conditions

There was no NH_3 data available for the Yolo or Lisbon Toe Drain boundaries – values were set at 0.03 and 0.04 mg L^{-1}, respectively. Time series for the Mokelumne, Calaveras and Cosumnes River boundaries were synthesized by Water Year Type using the available years in the Dahlgren dataset.

Time series of data were available through BDAT for Martinez and the Sacramento and San Joaquin Rivers.

8.4.2 Nitrate

There was no NO_3 data available for the Yolo or Lisbon Toe Drain boundaries – values were set at 0.09 mg L^{-1}. Time series for the Mokelumne, Calaveras and Cosumnes River boundaries were synthesized by Water Year Type using the available years in the Dahlgren dataset.

Time series of data were available through BDAT for Martinez and the Sacramento and San Joaquin Rivers. For the Sacramento boundary, data from Greenes Landing and Hood were merged, but the values were decreased by a factor 0.825. Further discussion on setting the Sacramento boundary condition for NO_3 is found in Appendix in Section 17.8.

8.4.3 Organic-N

There was no organic-N data available for the Yolo or Lisbon Toe Drain boundaries – values were set at 0.2 mg L^{-1}. Time series for the Mokelumne, Calaveras and Cosumnes River boundaries were synthesized by Water Year Type using the available years in the Dahlgren dataset.

Time series of data were available through BDAT for Martinez and the Sacramento and San Joaquin Rivers. For the Sacramento boundary, data from Greenes Landing and Hood were merged.

8.4.4 Chlorophyll a/Algae

There was no chl-a data available for the Yolo or Lisbon Toe Drain boundaries – values were set at 0.2 mg L^{-1}. Chl-a time series for the Mokelumne, Calaveras and Cosumnes River boundaries were synthesized by Water Year Type using the available years in the Dahlgren dataset, and corrected for use in the model as biomass of algae as described in Sections 5.5.2.and 5.2.4.

Time series of data were available through BDAT for Martinez and the Sacramento and San Joaquin Rivers. For the Sacramento boundary, data from Greenes Landing and Hood were merged.

8.4.5 Nitrite and Organic-P

There was no organic-P data available through BDAT and only a limited amount of NO_2 data. Values for organic-P and NO_2 were set using a combination of data sources, including previously used values in DSM2, BDAT and Dahlgren's dataset.

At Freeport, examination of the SRWWTP measurements for NO_2 (Table 17-5) and Dahlgren's measurements yielded that a reasonable value was 0.004 mg L^{-1}. At Vernalis, Dahlgren's average NO_2 measurement was reduced by an order of magnitude to 0.15 mg L^{-1}. The Martinez boundary was set to 0.008 mg L^{-1}. The Yolo and Lisbon Toe Drain were set at 0.004 mg L^{-1}, the Mokelumne R. was set at 0.004 mg L^{-1} and the other two river boundaries set at 0.005 mg L^{-1}.

Organic-P measurements were set at 0.01 mg L^{-1} at Martinez, Yolo and Lisbon Toe Drain. Some values were available in Dahlgren's dataset which were used to synthesize monthly values data by water year type for the Sacramento, San Joaquin, Mokelumne, Calaveras and Cosumnes River boundaries.

8.4.6 DO

DO boundary conditions were set using continuous time series of measurements, the only nutrient for which regular time series of data were available, although not for the entire modeled time span. Sacramento River boundary DO time series were used at the Sacramento boundary and also at the Yolo and the Lisbon Toe Drain boundaries. Because measurements were not available for every modeled year, hourly time series were synthesized using Water Year Type as a guide. Missing data were filled as described in Section 6.6.4.

Martinez and the San Joaquin River each had time series of data available for DO boundary conditions. The Mokelumne and Cosumnes and River boundaries were set at a constant 9.0 mg L^{-1}, and the Calaveras R. boundary at 7.0 mg L^{-1}. DICU drains were set at a constant DO concentration of 5.1 mg L^{-1}, the value used in previous DO studies (Rajbhandari, 2003).

8.4.7 Ortho-phosphate

Values for PO_4 were set using a combination of data sources including USGS, BDAT and Dahlgren data sets. Time series of values were synthesized by Water Year Type using data available in Dahlgren's data set for the Cosumnes, Calaveras and Mokelumne Rivers. Yolo and Lisbon Toe Drain boundary PO_4 values were set at 0.1 mg L^{-1}.

Time series of data were available from BDAT for setting the San Joaquin River boundary values. BDAT time series data for the Martinez boundary was supplemented with USGS data as a check on values. For the Sacramento River, time series of data were available at Greenes Landing and Hood. The values were merged then reduced by a factor of 0.7 for use as a boundary condition.

8.4.8 CBOD

There were a few measurements available on BDAT for Biochemical Oxygen Demand, or BOD, at the Sacramento River near Freeport and on the San Joaquin River downstream of Vernalis, mostly prior to 1990. The available values were averaged and transformed into CBOD using regression relationships derived from Stockton WWTP measurements, where both BOD and CBOD data measurements were made. The relationship between CBOD and BOD is discussed in Appendix Section 17.3. CBOD values were then set to these averages as constants at each boundary. The Sacramento boundary was set at 1.2 mg L^{-1}, the San Joaquin and Martinez boundaries were set at 2.8 mg L^{-1}, the Mokelumne R. was set at 1.1 mg L^{-1}, and the other Delta inflow boundaries were set at 1.5 mg L^{-1}.

8.5 Nutrients - DICU

Constituent concentrations for the DICU locations were set as constants. Values selected for the prior nutrient model efforts (Rajbhandari, 2003) were accepted with no modification.

8.6 Nutrients – Effluent Boundaries

Data were gathered from a variety of sources for setting boundary conditions at WWTP effluent locations. Data were processed to yield daily, bi-weekly or monthly values to use as boundary conditions. When data gaps appeared in time series data, either average values or data synthesized by Water Year type were used to fill the gaps. Bi-weekly data were either extended into daily data or compressed into monthly data. Missing years were either filled with constant values, or with a time series using effluent data from the same Water Year Type.

Because of QUAL's limit on the number of boundary conditions it can process as instantaneous (15 minute), hourly or daily time steps, effluent data from sources with small inflow volume was occasionally treated as a monthly value or a constant even when more frequent data were available over part of the modeled time span. In some cases, data were extended into 15-minute time series if averaging was not desirable.

Salinity (EC) measurements were not recorded for the effluent at some WWTP's. In this case, model output was sometimes used to synthesize an EC boundary condition for the effluent. QUAL EC output time series at the effluent source location was reintroduced at the effluent node. This approach meant that effluent EC did not change QUAL modeled (historical) EC at those locations.

Figure 17-35 through Figure 17-39 are plots of effluent concentrations for all of the constituents for Sac Regional and Stockton WWTPs.

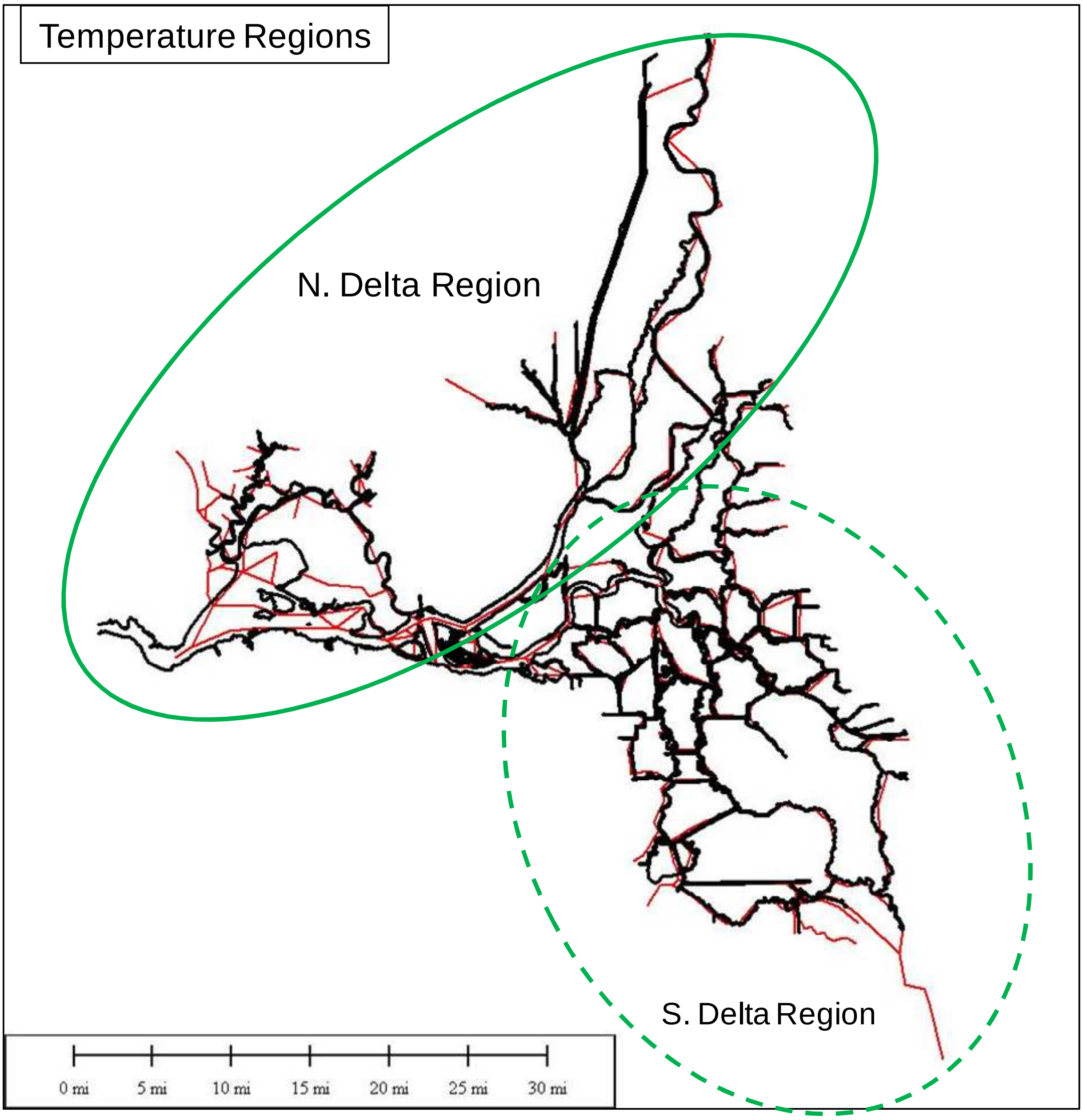


Figure 8-1 A minimum two meteorological regions are needed to calibrate QUAL for water temperature.

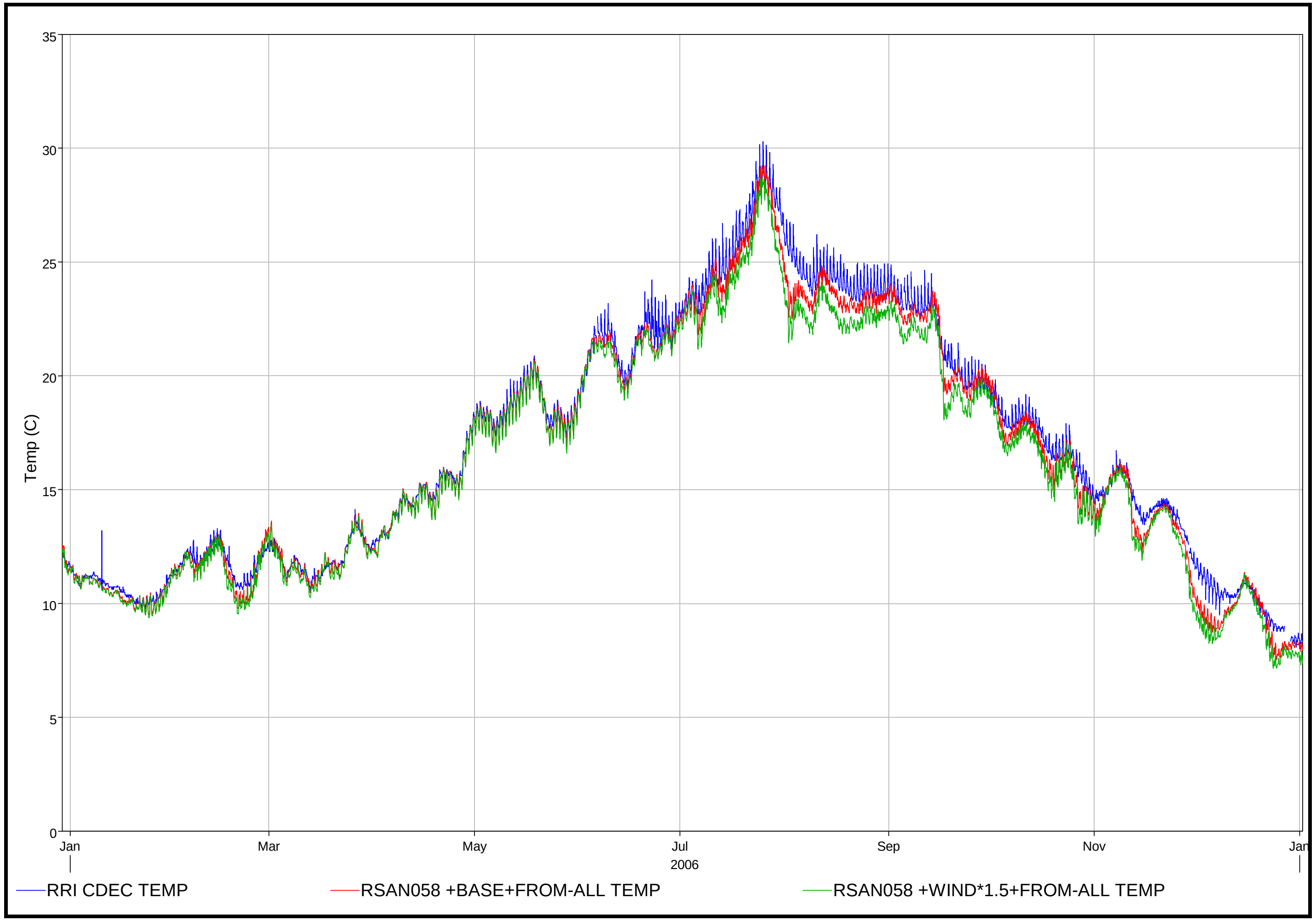


Figure 8-2 Modeled water temperature at RSAN058 on the San Joaquin River for two wind speeds – Base speed and wind speed*1.5 – in comparison with data (blue line).

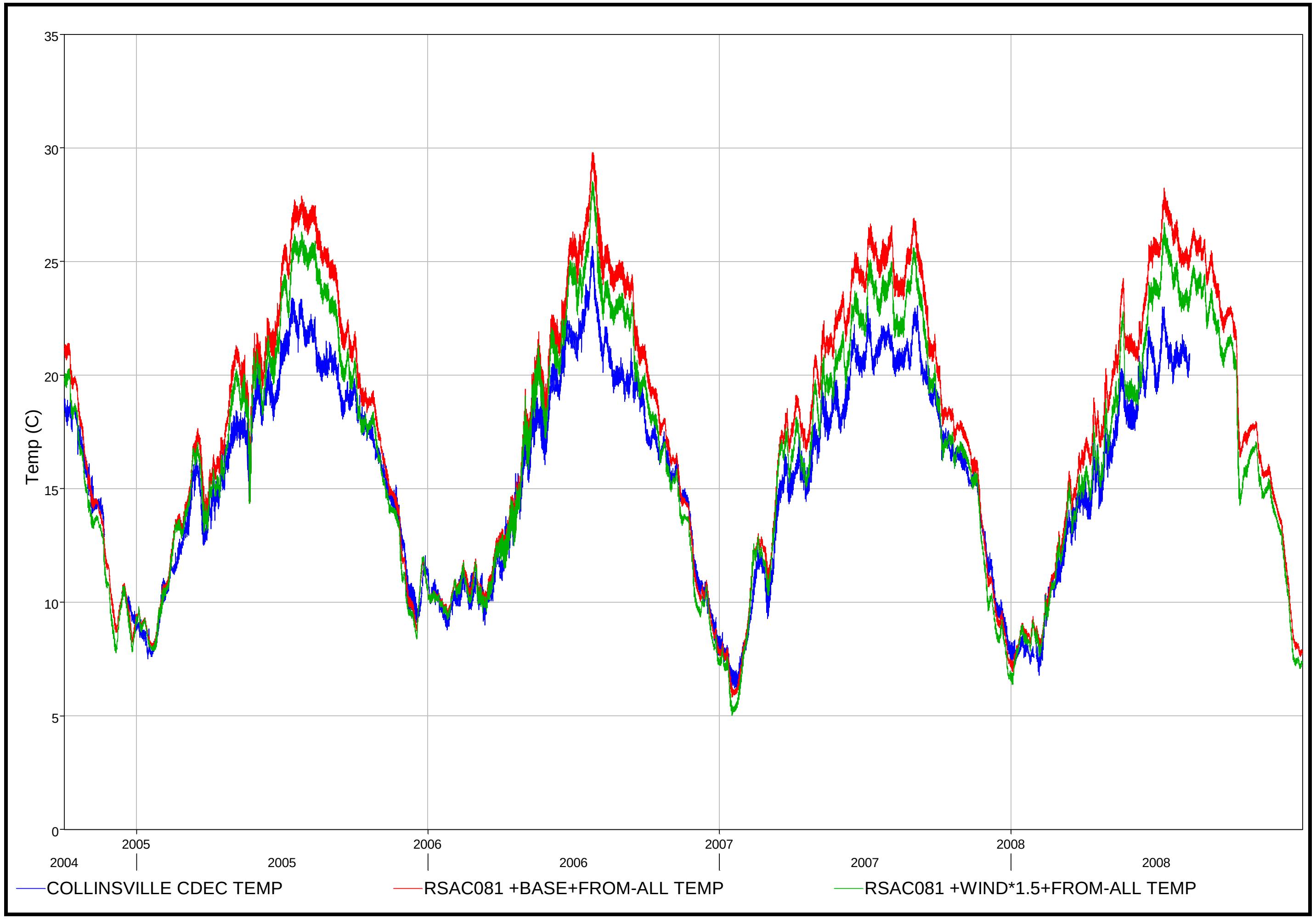


Figure 8-3 Modeled water temperature at RSAC081 for two wind speeds – Base and wind speed*1.5, *vs.* data (blue line). Increasing wind speed produces a better fit to the data.

9 Chemical Speciation Modeling and Isotope Analysis

9.1 EQ3/6 modeling

Measurement data supplied by R. Dahlgren (U.C. Davis) was used to develop chemical speciation models using the EQ3/6 program. A complete suite of water quality constituents were measured in the data at each location shown in Figure 7-4. Using Dahlgren's measurements, EQ3/6 models (Wolery, 1992) were developed to investigate general trends in the water chemistry, and the speciation of constituents in solution at Vernalis and Freeport. The details of model formulation and the speciation results are covered in Appendix Section 17.10.

Initial calculations using equilibrium constants for the ammonia dissociation reaction, assuming water temperature at 25°C, were made to assess the range of NH_3 (*aq*) and NH_4^+ concentrations that are likely to be found in the Delta. At the pH levels normally found in the Delta, pH = 7.0 – 8.0, calculations yield that less than 1.0% and less than 6.0%, respectively, of the total ammonia in solution would be found as NH_3(*aq*). As a simplification given the long time frame modeled, apart from extreme events, it is reasonable to assume that the ammonia modeled in QUAL is predominantly NH_4^+. If a short time frame event were to be modeled or examined, that assumption would not necessarily be justified, depending on the conditions. In the Dahlgren measurements, pH at Vernalis varied between 7.4 and 7.6, and at Freeport, pH varied between 7.3 and 8.3.

The speciation calculations were used as a heuristic to understanding the chemistry of waters entering the Delta at its major inflow boundaries. Clearly, due to biological activity constituent concentrations these waters are not at equilibrium as the model calculations assume. However, several interesting features of the calculations were noted. First, the average pH of the incoming waters was near pH = 8.0, so most of the ammonia in solution was NH_4^+, as discussed in Appendix Section 17.10. Nitrate concentration was at the same order of magnitude as NH_4^+ concentration, while nitrite was two orders of magnitude less. On average, the NH_4^+ concentration in the incoming water is approximately in the range considered as critical for algal uptake of NO_3 *vs*. NH_4^+ (Dugdale et al., 2007; Wilkerson et al., 2006)).

Interaction between the CO_2 in the atmosphere and surface waters can sometimes be an important factor in determining the pH of surface water, as the gas dissolves into the water and dissociates. In the EQ3/6 speciation calculations, it was found that on average the water was supersaturated with respect to CO_2(g) in comparison with the concentration expected if the solutions were at equilibrium with the atmosphere. This higher concentration of CO_2(g) in solution is (nearly certainly) due to biological activity from algal respiration. As a consequence, we can expect that the waters would be out-gassing CO_2, not gaining it from atmospheric interactions. This biological activity would tend to continue as waters travel through the Delta, as the contribution of new nutrient sources within the Delta would tend to promote continued biological activity. Thus, the mass transfer of atmospheric CO_2 into the water is not likely to be a primary factor regulating the pH of Delta waters.

The implication of this observation is that changing the conceptual model formulation in QUAL to include the mass transfer of atmospheric CO_2 into the water would not be considered a high priority at the Delta-wide spatial scale, and at the long time frame considered in the initial calibrated model, 1990 - 2008. At shorter time frames and at smaller spatial scales, i.e. if considering a "local" model, this simplification may not be justified.

9.2 Isotope Analysis

In Kendall's CALFED-funded PIN700 project "Determination of Sources of Organic Matter and Nutrients in the San Joaquin River" (Kendall et al., 2008), samples collected from 33 sites in the San Joaquin and Sacramento Rivers from 8/06 to 5/08 were analyzed for NO_3, POM (particulate organic matter, which is mostly comprised of algae and bacteria), DOC, and other isotopes to determine the seasonal and spatial changes in the sources of NO_3 and POM, and in the link between NO_3 and POM. Analysis of the NO_3 and POM for $\delta^{15}N$ showed that the $\delta^{15}N$ of algae is sensitive to the nutrient sources, extent of nitrification of NH_4 to NO_3, and instream biogeochemical processes.

Because analysis of the data is not complete, the synthesis of model and data cannot yet be completed.

10 Calibration and Validation

10.1 General Methodology

Water temperature was calibrated independently of nutrients, as temperature influences nutrient dynamics but not *vice versa*.

Several factors guided calibration methodology and the selection of time periods for calibration and validation. The most important factor was the availability and quality of calibration data, and the second was the need to include a variety of inflow conditions, as represented by Water Year Type, to identify variations in model calculations due to factors such as outflow volume and reservoir releases, as well as Delta operations such as meeting X2 salinity targets or the use of the Delta Cross Channel gates.

Another factor was the need to develop and test a methodology consistent with possible future uses of the calibrated model, where measurement data may not exist to inform the boundary conditions. In the two likely routes for future model development, covering a Historical time frame before 1990 or a nutrient Planning Model which currently covers the period from 1922 – 2003, there are few or no nutrient and effluent measurements available. These models could be used to quantify the effect on hydrodynamics and water quality of a shift in Delta dynamics, such as the introduction of invasive species or of a modification in the Delta water regime such as construction of a new gate.

The only measurement that is available over extended time spans is outflow, from rivers into the Delta and Delta outflow, so a practical constraint for setting boundary conditions is that they should mainly rely on relationships with flow or be set mainly in accord with Water Year type. Thus in order to synthesize data for any time period, having a methodology for representing boundary conditions by Water Year Type without the corresponding data becomes a sensible strategy.

The time periods selected for water temperature calibration are shown in Figure 10-1, and the availability and quality of data illustrated in Figure 17-26 through Figure 17-28. Temperature data coverage was adequate spatially, apart from the Yolo/Cache and Suisun Marsh areas, and data were available at either hourly or daily time intervals. Data quality was variable over the modeled time span, and both availability and quality were greater after 2000. Data from different sources sometimes overlapped spatially, and the comparisons were helpful is establishing an expected temporal variability and a range in measurement magnitude.

The time periods selected for nutrient calibration are shown in Figure 10-2, and the availability and quality of data are illustrated in Figure 7-1 through Figure 17-14. The great disparity in the availability of boundary condition data for the various WWTPs complicated the selection of calibration and validation periods for nutrients. For all but two of the WWTPs, boundary condition data were only available in recent years. Nutrient data coverage had similar spatial coverage to temperature data. Unlike temperature data, nearly all nutrient model measurements were taken as grab samples, and temporal coverage was basically monthly (sometimes less). Data quality was generally very good over the entire modeled time span (1990 – 2008), although for many sites there was more data 1990 – 1995 than in later periods.

Both graphical and statistical model evaluation techniques were used in the analysis of calibration and validation results. Different techniques and strategies were used for temperature calibration and validation than for the nutrient model, as the data availability was very different between the two.

10.2 Calibration and Validation of QUAL for Water Temperature

10.2.1 Methodology for Water Temperature Calibration and Validation

Because the meteorological data from the previous calibration (Rajbhandari 2003) models water temperature the South Delta region adequately, the focus of the current water temperature calibration was the North Delta region. Once the application of meteorological data is "regionalized" in future versions of DSM2, a calibrated two-region water temperature model should be available using the current calibration for the North Delta and the previous calibration for the South Delta.

A sensitivity analysis showed that water temperature was most sensitive to variation in wind speed. As discussed in Sections 8.1 and 8.3, wind speeds prior to 1996 were taken from the CIMIS Brentwood location which generally had a much higher average wind speeds than the Stockton NOAA data. Wind speeds from 1990 - 1995 were thus decreased in value by a factor of 0.85 so the average wind speed matched the average from 1996 – 2008. In addition, wind speed was increased by factor of two each year from April – October, with a linear ramp up/ramp down period of three days.

Five sub-regions were selected for calibration/validation comparison – along the San Joaquin River corridor, along the Sacramento River corridor, the South Delta, the Yolo region and Suisun Marsh (Figure 10-3). Only one measurement location was available in the Yolo and Suisun regions, so they are characterized by those points.

10.2.2 Residual Analysis – Water Temperature

Residuals were calculated as (Data – Model) for each calendar year at each location, and are grouped by Water Year Type. Although Water Years begin in October of the previous year, the final Water Year Type is finalized several months later after a portion of the wet season reveals the likely depth of the snow pack. Although grouped by Water Year, statistics were calculated on an annual time frame, under the assumption that decisions on water operations October - December may be based on factors from the previous water year (the same calendar year) such as reservoir levels, particularly in drier years.

Residual results were calculated for each location in each region – for the Suisun and Yolo regions, only a single location was available. For each statistic, an average result was calculated, and the maximum and minimum results identified. The following statistics were used for comparison of calibration and validation results: Residual mean and standard deviation, mean square error (MSE), root mean square error (RMSE), Nash-Sutcliff efficiency (NSE), percent bias (PBIAS), and RMSE-standard deviation ratio (RSR). The reasoning behind this methodology is discussed in Appendix Section 17.9.

10.2.3 Calibration/Validation Results for Water Temperature

Table 17-9 through Table 17-12 document the water temperature calibration and validation results by region and by four Water Year Types. Because only one Below Normal Water Year occurred during the modeled time span, calibration and validation periods could not be selected for comparison although results are shown in the Appendix in Table 17-14.

Results for the validation period are essentially indistinguishable from the calibration period. For the Sacramento region, the calibration results are excellent and they are very good for the other regions. Generally speaking, summer water temperatures were low in the San Joaquin and South Delta regions.

Ranges for model calibration performance ratings for the NSE, RSR and PBIAS statistics under monthly time steps are given in (Moriasi et.al., 2007). Following those general guide lines, a calibration is viewed as “Very Good” for the NSE statistic if NSE is greater than 0.75. Similarly, a PBIAS value less than +/-(10 – 25)% (depending on category such as streamflow, sediment or N,P constituent) and a RSR value less than 0.50 are “Very Good”. Under each of these three criteria, both the calibration and the validation of water temperature is “Very Good” in all five regions over all Water Year types.

Figure 17-53 through Figure 17-66 illustrate some of the results of the calibration and validation of QUAL for water temperature at several locations for each water year type except Below Normal, where only one year of data were available. Figures show a comparison of model (red line) and data (blue line) in the upper plot, the residual (center plot), and the histogram of the residual (lower plot). In the upper plot, vertical blue lines are missing data points (not included in any calculation).

In the central and south Delta the residual histograms tend to be skewed positively indicating model under-prediction, while along the lower Sacramento R. the histograms tend to be skewed to negative values, indicating the model values were too high (Figure 17-54, Figure 17-57, Figure 17-62, Figure 17-65). On either side of Three Mile Slough, the model calculations are not skewed and the model predictions are very good (Figure 17-53, Figure 17-56, Figure 17-59, Figure 17-63)

10.3 Calibration and Validation of QUAL for nutrients

10.3.1 Methodology for Nutrient Calibration and Validation

Although data were available at many locations over portions of each of the calibration and validation periods, only data that spanned the years 1992 – 2008 was used for calibration and validation. The majority of this data were from EMP locations, although a few constituents were available from other agencies. Under these criteria, there was no BOD/CBOD data available for calibration and validation over the selected time span. BOD measurements were lacking except in a short reach along the San Joaquin River, and these were limited in the temporal frame. There were essentially no measurements for organic-P and the measurements for nitrite and nitrate individually were sparse.

Because nutrient data were only available on a monthly basis and the number of values available was limited, only two types of hydrologic conditions were considered. The Wet type is composed of Wet and Above Average Water Year types, while the Dry type is composed of Critically Dry, Dry and Below Average Water Year types.

Figure 17-67 through Figure 17-70 illustrates the final set of locations that were used, although not all of the nutrients had data available at each location. Nitrate and nitrite were combined in model output, as the measurement of NO_3+NO_2 was common and available over the entire model period. Figure 17-15 through Figure 17-18 show the full set of data locations, not all of these were used for various reasons (NOTE – these measurement locations are shown in the RMA model 2-D grid).

Calibration of the nutrient model entailed setting the parameters discussed in Section 5 and listed in Table 5-2 and

Table 5-3, as well as setting constituent values at boundaries where no data or only limited data were available. The Tables list the range of values used in calibration. Although there was some iteration between setting the global parameters and the regional parameters, the global parameters were only changed slightly in value after an initial acceptable value was chosen.

Values for nutrient boundary conditions at unconstrained boundaries, notably in the Yolo/Cache region, were also set well before the fine-tuning of parameters was complete.

As a strategy, a minimum number of reaction rates were varied as this generally will result in a model with better prediction power – i.e., it avoids over-fitting. Four regions were selected initially as a basis for setting regionally-based parameters, although these were later refined to the 20 regions shown in Figure 17-67 through Figure 17-70. There was a limited amount of variation of parameter values within these regions. For example, channels adjacent to the location Suisun at Volanti (not included in calibration statistics) were fine-tuned to optimize the model fit there.

The underlined, **bold** parameters were the primary parameters varied during the calibration:

- Algal rates:
  - **Growth (max), Mortality**, Settling, Respiration
- Decay rates:
  - **Ammonia, Nitrite**, CBOD, **Organic-P**
  - Hydrolysis: Organic-N to NH_3
- Settling rates:
  - CBOD, Organic-N, **Organic-P**
- Benthic:
  - **Oxygen Demand (SOD)**
  - **Release of PO_4, NH_3**
- Oxygen reaeration

Parameter values were chosen within ranges documented in the literature – SOD is the only exception. The ranges for maximum growth rate (day^{-1}) for algal species vary widely: for diatoms from 0.3 to 3.4; for green algae from 0.6 to 9.0; for golden-brown algae from 0.4 to 2.9; for Dinoflagellates from 0.3 to 2.1; for cyanobacteria from 0.07 to 11.0. The values are either gross or net production rates and were measured at a range of temperatures (see references in Cole and Wells, 2008).

In P-limited environments, Grover (in: Cole and Wells et al., 2008) measured maximum algal growth rates that were between 0.5 and 1.0 day^{-1}, and P-half-saturation constants from 6.0 E-0.6 to 0.0015 mg L^{-1}. In Cole and Wells (2008), the reported range of literature values for P-half-saturation constants varied from 0.001 to 1.5 mg L^{-1}, and for N-half-saturation constants from 0.01 to 4.3 mg L^{-1}, with the highest values reported for experiments using NO_3 and the highest reported rate for NH_3 experiments was 0.14 mg L^{-1}.

Under varying light intensities (factor of two), Litchman (in: Cole and Wells et al., 2008) measured maximum algal growth rates from 1.2 to 1.4 day^{-1} and respiration rates from 0.001 to 0.6 day^{-1}. CE-QUAL-W2 uses a default value of 0.04 day^{-1} for algal respiration rate, and suggests a maximum mortality rate of 10% of the maximum algal growth rate. The default value for algal mortality was 0.1 day^{-1}, with a range of 0.03 to 0.3 used in previous studies.

10.3.2 Residual Analysis - Nutrients

The combined effects of data variability between agencies and sparse measurement intervals, generally monthly, meant that some measure of uncertainty needed to be included in assessing the quality of model calibration. The EMP and USGS had data along the Sacramento River at the same or similar measurement locations, as discussed in Section 6.3, and the variability between the measurement data sets indicated that daily fluctuations, tidal influences and extreme events could influence the value.

To capture this variability, an “envelope” of model values was used to incorporate these different sources of uncertainty. The maximum and minimum monthly values of hourly model output were calculated to create the upper and lower bounds of the envelope, respectively. At a given location, if the calibration data fell within that max/min envelope, then the residual was calculated as zero. Values falling outside of the envelope were calculated as residuals using the either the maximum of the envelope (data higher than maximum value) or the minimum value of the envelope (data less than the minimum value) for that month. Note that this methodology could be refined, as the partition of data and model values along strict monthly time intervals in somewhat artificial. However, for simplicity, the monthly approach was deemed reasonable.

For the six constituents used in the calibration – NH_3, NO_3+NO_2, organic-N, DO, chl-a/algae, and PO_4 – calibration statistics were calculated at each available location. Histograms of the residuals were also prepared.

Technical detail on the statistics and methodology used in the analysis of residuals in calibration and validation is discussed in Appendix Section 17.9.

10.3.3 Calibration/Validation Results for Nutrients

Table 10-1 through

Table 10-3[14] list the results of the calibration/validation – in these tables, the quality of the calibration was assessed at each location using the methodology detailed in Appendix Section 17.9. Using these criteria, the quality of a calibration can be rated from Very Good (VG) to Unsatisfactory (U) for individual constituents (Moriasi et al., 2007).

The calibration and validation results for NH_3, NO_3+NO_2, and DO are rated from Very Good to Satisfactory at most locations for both Dry and Wet year types for the three criteria with only a few exceptions. The results for algae are also in this range, although there are more Unsatisfactory results for the RSR statistics particularly in the calibration Wet year type.

Unsatisfactory results tended to be grouped at a few locations over all nutrients, with Grizzly Bay and Disappointment Slough having the worst results, followed by Potato Point and Old River at RDR. Organic-N and PO_4 had the worst results, which is not surprising for PO_4 as there were no organic-P measurements to help constrain this nutrient. Also, organic-P and organic-N are each consumed during algal growth, so the lack of the compensating organic-P measurement necessarily affected the ability to calibrate organic-N.

Overall, the model calibration is rated Very Good to Satisfactory for all constituents at all locations, as there is no location with Unsatisfactory results across all three criteria. The worst results occurred in areas where there were the fewest measurements near-by to constrain upstream or local parameterizations. Validation and calibration results are very similar, although validation statistics were somewhat better, probably because more very recent years were included. The recent years tended to have better quality of measurements.

10.3.4 Nutrient Model Results: Calibration/validation Figures

These figures are numerous, and so supplied in four separate documents as Appendices. Figures were produced at all locations where there was sufficient data to plot more than a couple years. Where data were available for (nearly) the full model term, plots were produced for the full time span and the spans 1990 – 1999 and 2000 – 2009. Model plots sometimes begin in May or June 1990, as at some locations the initial condition values were somewhat too high or too low and the model required a spin-up at those locations for the first few months. The figures are organized by constituent.

[14] Each category of measurement – dry or wet and calibration or validation – had at least 36 measurements, i.e., $N \geq 36$. Many categories had significantly larger values of N.

The first document, Appendix II, contains ammonia and nitrate+nitrite model results vs. measurements, the second document, Appendix III, contains DO and algae, and the third, Appendix IV, contains PO_4 and organic-N. The final document, Appendix V, contains figures with calibration histograms and residuals.

10.4 Discussion of Calibration and Validation

There is no unique way to calibrate a model with this many parameters (48), and numerous unconstrained or poorly constrained boundaries, such as the Yolo/Cache Slough/Liberty Island region. However, the final parameterization of the model is arguably sensible, as parameter values are generally within literature ranges and unconstrained boundaries were set at reasonable values. In addition, the calibration results are very good for those constituents that had the best constraining data, and generally satisfactory for the other constituents. In fact, the calibration for algae is remarkably good given the sparse data and the important factors in their dynamics not included in the model, such as loss to clams. The criteria applied for nutrient calibration assessment are likely too strict, as they were developed for parameters with lower uncertainty than nutrients.

If the application of meteorological data is “regionalized” in future versions of DSM2, a calibrated two-region water temperature model will be available using the current calibration for the North Delta and the previous calibration for the South Delta (Rajbhandari, 2003). Even with the current single region model, the calibration statistics are very good (although regionally biased) despite the large amount of synthesized data.

Two large areas of the model domain, shown in Figure 17-18, have almost no nutrient measurements to constrain the setting of boundary conditions or parameters in those regions. Suisun Marsh has a few measurements but the Yolo/Cache region has none. This presented difficulties in calibrating the model in those regions, and in the case of the Yolo/Cache region, downstream nutrient concentrations could be strongly affected by the boundary conditions selected.

Although some effort went into identifying the cause of extreme events in the data, such as a large spike in algal mass, the length of the time period (19 years) precluded detailed analysis.

Temperature Validation					Temperature Calibration				
1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
5	4	2	2	4	3	4	5	2	1

	Temperature Validation		Temperature Calibration					
1990	1991	1992	1993	1994	1995	1996	1997	1998
1	1	1	4	1	5	5	5	5

1	Critical
2	Dry
3	Below Normal
4	Above Normal
5	Wet

(cyan)	Calibration
(orange)	Validation

Figure 10-1 Temperature model calibration and validation periods. Data 1999 – 2008 was generally of better quality, but early Critical Water Years ("1" in the chart) were also used.

Nutrient Calibration/Validation Periods

Nutrient Calibration				Nutrient Validation		Nutrient Calibration		Nutrient Validation	
1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
5	4	2	2	4	3	4	5	2	1

		Nutrient Calibration		Nutrient Validation				
1990	1991	1992	1993	1994	1995	1996	1997	1998
1	1	1	4	1	5	5	5	5

1	Critical
2	Dry
3	Below Normal
4	Above Normal
5	Wet

(blue)	Calibration
(red)	Validation

Figure 10-2 Nutrient calibration (blue) and validation (red) periods.

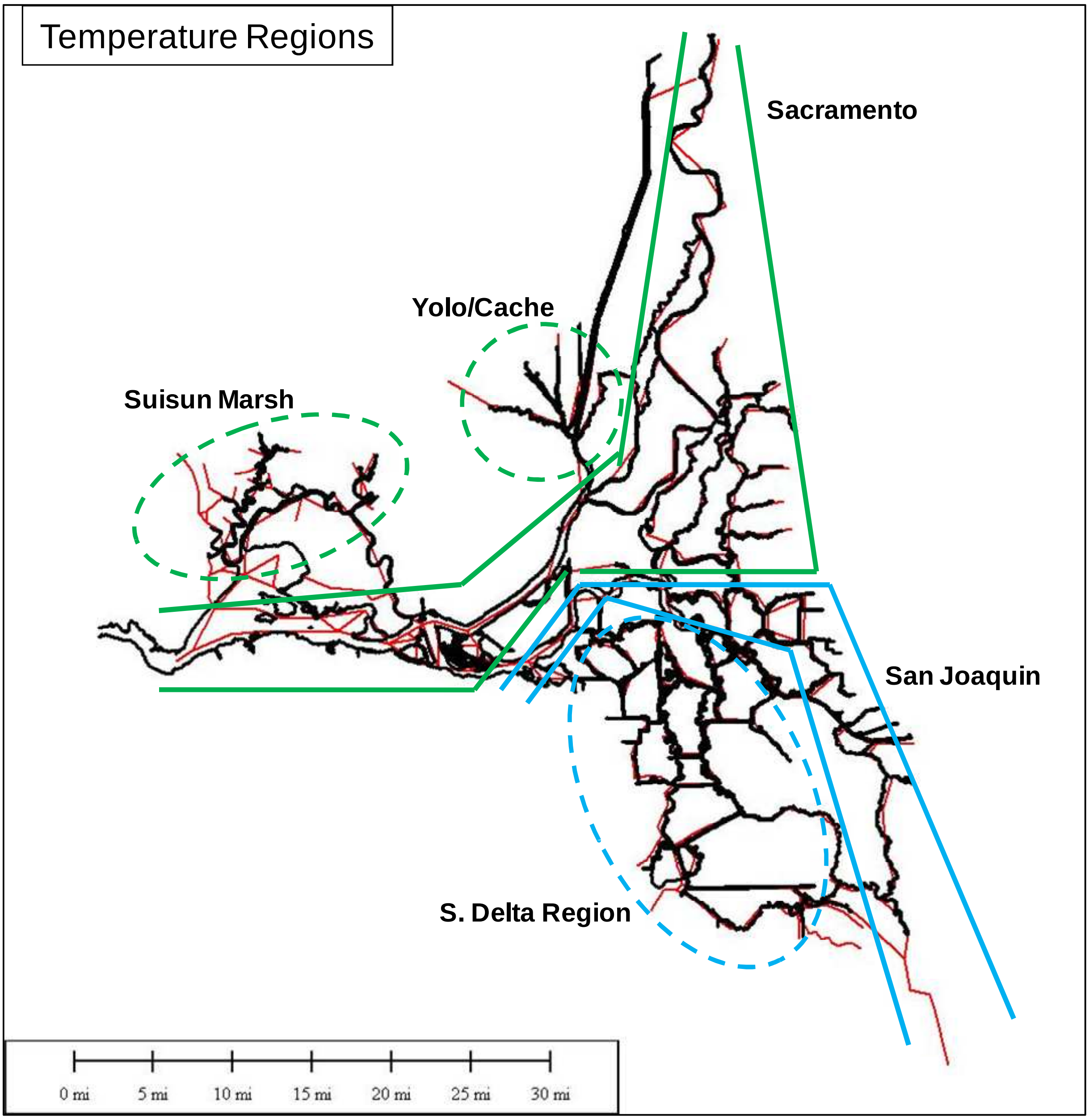


Figure 10-3 Five regions were used in the calibration and validation of water temperature.

Table 10-1 Calibration/Validation results for NH_3 and NO_3+NO_2: VG=Very Good, G=Good, SAT=Satisfactory and U=Unsatisfactory, in red font.

Ammonia

Calibration - Dry	NSE	PBIAS	RSR	Validation - Dry	NSE	PBIAS	RSR
Susiun near Nichols	VG	VG	VG	Susiun near Nichols	VG	VG	VG
Grizzly	U	VG	U	Grizzly	U	VG	U
Potato Point	SAT	VG	SAT	Potato Point	VG	VG	SAT
Old River at RDR	SAT	VG	U	Old River at RDR	VG	VG	G
Point Sacramento	VG	VG	VG	Point Sacramento	VG	VG	VG
Buckley Cove	VG	VG	VG	Buckley Cove	VG	VG	VG
Greens/Hood	VG	VG	VG	Greens/Hood	VG	VG	VG
Disappointment Sl.	U	VG	U	Disappointment Sl.	SAT	VG	U
Calibration - Wet				Validation - Wet			
Susiun near Nichols	VG	VG	VG	Susiun near Nichols	VG	VG	VG
Grizzly	U	VG	U	Grizzly	U	VG	U
Potato Point	VG	VG	VG	Potato Point	VG	VG	VG
Old River at RDR	SAT	VG	U	Old River at RDR	U	VG	U
Point Sacramento	VG	VG	VG	Point Sacramento	VG	VG	VG
Buckley Cove	VG	VG	VG	Buckley Cove	VG	VG	VG
Greens/Hood	VG	VG	VG	Greens/Hood	VG	VG	VG
Disappointment Sl.	SAT	VG	U	Disappointment Sl.	U	VG	U

NO3+NO2

Calibration - Dry	NSE	PBIAS	RSR	Validation - Dry	NSE	PBIAS	RSR
Susiun near Nichols	SAT	VG	U	Susiun near Nichols	SAT	VG	U
Rio Vista	VG	VG	VG	Rio Vista	VG	VG	VG
Grizzly	U	VG	U	Grizzly	SAT	VG	SAT
Potato Point	SAT	VG	SAT	Potato Point	G	VG	G
Old River at RDR	SAT	VG	U	Old River at RDR	G	VG	G
Point Sacramento	SAT	VG	U	Point Sacramento	SAT	VG	U
Buckley Cove	VG	VG	G	Buckley Cove	VG	VG	VG
Greens/Hood	VG	VG	VG	Greens/Hood	VG	VG	VG
Disappointment Sl.	SAT	VG	U	Disappointment Sl.	SAT	VG	SAT
Calibration - Wet				Validation - Wet			
Susiun near Nichols	SAT	VG	SAT	Susiun near Nichols	SAT	VG	U
Rio Vista	VG	VG	VG	Rio Vista	VG	VG	VG
Grizzly	G	VG	G	Grizzly	G	VG	G
Potato Point	VG	VG	VG	Potato Point	VG	VG	VG
Old River at RDR	G	VG	G	Old River at RDR	VG	VG	G
Point Sacramento	VG	VG	VG	Point Sacramento	G	VG	G
Buckley Cove	VG	VG	VG	Buckley Cove	VG	VG	VG
Greens/Hood	VG	VG	VG	Greens/Hood	VG	VG	VG
Disappointment Sl.	VG	VG	VG	Disappointment Sl.	VG	VG	VG

Table 10-2 Calibration/Validation results for Org-N and DO: VG=Very Good, G=Good, SAT=Satisfactory and U=Unsatisfactory, in red font.

Organic-N

Calibration - Dry	NSE	PBIAS	RSR	Validation - Dry	NSE	PBIAS	RSR
Susiun near Nichols	U	VG	U	Susiun near Nichols	U	VG	U
Grizzly	U	VG	U	Grizzly	U	VG	U
Potato Point	U	VG	U	Potato Point	U	VG	U
Old River at RDR	U	VG	U	Old River at RDR	SAT	VG	U
Point Sacramento	U	VG	U	Point Sacramento	U	VG	U
Buckley Cove	SAT	VG	SAT	Buckley Cove	U	VG	U
Greens/Hood	VG	VG	VG	Greens/Hood	VG	VG	VG
Disappointment Sl.	U	Sat	U	Disappointment Sl.	U	G	U
Calibration - Wet				Validation - Wet			
Susiun near Nichols	SAT	VG	U	Susiun near Nichols	G	VG	G
Grizzly	U	VG	U	Grizzly	SAT	VG	U
Potato Point	SAT	VG	U	Potato Point	SAT	VG	U
Old River at RDR	SAT	VG	U	Old River at RDR	SAT	VG	U
Point Sacramento	SAT	VG	U	Point Sacramento	VG	VG	G
Buckley Cove	VG	VG	VG	Buckley Cove	SAT	VG	U
Greens/Hood	VG	VG	VG	Greens/Hood	VG	VG	VG
Disappointment Sl.	U	Sat	U	Disappointment Sl.	U	G	U

DO

Calibration - Dry	NSE	PBIAS	RSR	Validation - Dry	NSE	PBIAS	RSR
Susiun near Nichols	VG	VG	VG	Susiun near Nichols	VG	VG	VG
Grizzly	VG	VG	VG	Grizzly	VG	VG	VG
Little Potato Sl at Terminous	U	VG	U	Little Potato Sl at Terminous	SAT	VG	U
Potato Point	VG	VG	VG	Potato Point	VG	VG	VG
Old River at RDR	VG	VG	VG	Old River at RDR	G	VG	G
Twitchell	VG	VG	VG	Twitchell	VG	VG	VG
Point Sacramento	VG	VG	VG	Point Sacramento	VG	VG	VG
Buckley Cove	U	Sat	U	Buckley Cove	VG	VG	VG
Greens/Hood	VG	VG	VG	Greens/Hood	VG	VG	VG
Calibration - Wet				Validation - Wet			
Susiun near Nichols	SAT	VG	U	Susiun near Nichols	VG	VG	VG
Grizzly	VG	VG	VG	Grizzly	VG	VG	VG
Little Potato Sl at Terminous	SAT	VG	U	Little Potato Sl at Terminous	U	VG	U
Potato Point	VG	VG	VG	Potato Point	VG	VG	VG
Old River at RDR	G	VG	SAT	Old River at RDR	G	VG	G
Twitchell	VG	VG	VG	Twitchell	SAT	VG	SAT
Point Sacramento	U	VG	U	Point Sacramento	G	VG	G
Buckley Cove	SAT	VG	U	Buckley Cove	U	Sat	U
Greens/Hood	VG	VG	VG	Greens/Hood	VG	VG	VG

Table 10-3 Calibration/Validation results for Chl-a/Algae andPO_4: VG=Very Good, G=Good, SAT=Satisfactory and U=Unsatisfactory, in red font.

Chl-a/Algae

Calibration - Dry	NSE	PBIAS	RSR	Validation - Dry	NSE	PBIAS	RSR
Point Sacramento	VG	VG	VG	Point Sacramento	VG	VG	VG
Susiun near Nichols	VG	VG	VG	Susiun near Nichols	VG	VG	VG
Rio Vista	G	VG	G	Rio Vista	VG	VG	VG
SJR at Pittsburg	SAT	VG	SAT	SJR at Pittsburg	VG	G	G
Buckley Cove	U	Sat	U	Buckley Cove	VG	VG	VG
Greens/Hood	VG	VG	VG	Greens/Hood	VG	VG	VG
Disappointment Sl.	SAT	VG	U	Disappointment Sl.	SAT	VG	U
Calibration - Wet				Validation - Wet			
Point Sacramento	U	VG	U	Point Sacramento	G	VG	G
Susiun near Nichols	U	VG	U	Susiun near Nichols	G	VG	SAT
Rio Vista	U	VG	U	Rio Vista	SAT	VG	U
SJR at Pittsburg	SAT	VG	U	SJR at Pittsburg	SAT	VG	U
Buckley Cove	SAT	VG	U	Buckley Cove	U	Sat	U
Greens/Hood	VG	VG	VG	Greens/Hood	VG	VG	VG
Disappointment Sl.	G	VG	G	Disappointment Sl.	VG	VG	VG

PO4

Calibration - Dry	NSE	PBIAS	RSR	Validation - Dry	NSE	PBIAS	RSR
Susiun near Nichols	SAT	Sat	U	Susiun near Nichols	SAT	Sat	U
Grizzly	U	VG	U	Grizzly	U	VG	U
Potato Point	U	VG	U	Potato Point	U	VG	U
Old River at RDR	SAT	Sat	U	Old River at RDR	SAT	Sat	U
Point Sacramento	U	VG	U	Point Sacramento	U	G	U
Buckley Cove	VG	VG	VG	Buckley Cove	VG	VG	G
Greens/Hood	VG	VG	VG	Greens/Hood	VG	VG	SAT
Disappointment Sl.	U	Sat	U	Disappointment Sl.	U	Sat	U
Calibration - Wet				Validation - Wet			
Susiun near Nichols	SAT	Sat	U	Susiun near Nichols	SAT	Sat	U
Grizzly	U	VG	U	Grizzly	U	VG	U
Potato Point	U	Sat	U	Potato Point	U	Sat	U
Old River at RDR	U	Sat	U	Old River at RDR	U	Sat	U
Point Sacramento	U	VG	U	Point Sacramento	SAT	VG	U
Buckley Cove	VG	VG	VG	Buckley Cove	VG	VG	VG
Greens/Hood	VG	VG	VG	Greens/Hood	VG	VG	VG
Disappointment Sl.	U	Sat	U	Disappointment Sl.	U	G	U

11 Volumetric Fingerprinting and Liberty Island Grid

11.1 Volumetric Fingerprinting Results

QUAL can be used to calculate a type of output called a volumetric fingerprint (Anderson, 2002). This calculation technique produces the relative contribution of various sources of water at any location in the model domain. At the Sacramento River boundary, for instance, all the water (100%) comes from that location, but at Rio Vista there will be additional volumetric contributions from the Sac Regional WWTP and from the Yolo Bypass boundary (and perhaps small contributions from the Eastside Rivers). Volumetric contributions are calculated for each source of water input as a flow boundary condition (including DICU). At any model location, the sum of the various sources of water will be 100%. Volumetric fingerprinting was performed using the calibrated model, and some model boundaries were combined for simplicity. The naming convention for the combined sources is found in Table 11-1. Figures illustrating volumetric fingerprinting are found at the end this section, and also in Appendix I Section 17.11.

Figure 11-1 shows that at Greens Landing, in additional to main volumetric contribution from the Sacramento R. boundary there are two lesser contributions, one from Sac Regional, ranging from near zero to about 4.0%, and the other from DICU sources, ranging from near zero to about 1.5%. Results are shown at a variety of locations in Figure 11-1, Figure 11-2 and (in the Appendix) Figure 17-71 through Figure 17-82, with a focus on volumetric contributions from effluent flows.

In general, the effluent volumes of most WWTPs are very small (less than 1.0%) at most locations examined. Stockton and Sac Regional have the largest contributions – Stockton WWTP volumes are only noticeable along the San Joaquin River. In both WWTPs, the volume contribution falls off with distance. Ag (DICU) inflows are also high in nutrients, and at some locations the Ag contributions are higher than WWTP volumes.

Along the lower San Joaquin and Sacramento Rivers, the volume of Sac Regional effluent is very similar at several locations (Figure 17-72). When Lisbon Toe Drain flows begin around 2004, the pattern of Sac Regional effluent volume changes in the Yolo region. In upstream areas of Cache Slough, AG volumes dominate until the Toe Drain flows begin (Figure 17-74). Sac Regional volumes remain higher year-round in the northern areas on the Mokelumne River.

On the lower Sacramento and San Joaquin Rivers, the volumetric contributions from other WWTP's is very small – this is illustrated in Figure 17-78. These volumes are lower than Sac Regional volumes (Figure 17-81).

11.2 Inclusion of Liberty Island

Recently, DSM2 was recalibrated in the area influenced by Liberty Island, which was flooded in 2000. The nutrient model was rerun under this new configuration to determine the influence this region would have on nutrient dynamics. The extended DSM2 grid[15], called the Liberty grid herein, is shown in Figure 11-3. The previous grid is referred to as the Base grid. Recall, the flows for the Lisbon Toe Drain were included from 2004 – 2008, as they were not available before that time.

Three output locations were included in model output for the constituents downstream of the Yolo inflow location, downstream of the outflow location for Liberty Island, and also at the end of Cache Slough (SLCCH016) at the location of a the temperature calibration time series. These three locations are shown in the DSM2 grid in Figure 11-4. Figures illustrating results are found at the end of this section, and also in Appendix I Section 17.11.

Large changes in comparison with the Base grid results were seen in all constituent concentration at the three locations in the Yolo/Liberty/Cache area (organic-P was not examined). Algal biomass, CBOD and organic-N increased at two of the locations, DO increased slightly, and the concentrations of each of the other constituents decreased in comparison with the Base grid. Yolo output is shown in Figure 11-5 through Figure 11-8, Liberty output is shown in Figure 17-83 through Figure 17-86, and SLCCH016 output is shown in Figure 17-87 through Figure 17-90. The results for the SLCCH016 location are quite different – it is located at the end of the grid (dead-end channel), and the constituent concentrations there are dominated by DICU flows.

Three locations are illustrated moving down the Sacramento River – RSAC101, RSAC092 and Point Sacramento (Figure 11-9 through Figure 11-12 and Figure 17-96 through Figure 17-100). Algal biomass increased in comparison with Base at all three locations, and all of the N-constituents decreased in concentration, although differences with the Base decreased with distance from the Yolo/Liberty area. At RSAC101 and RSAC092, CBOD and PO_4 were higher than Base concentrations. At Point Sacramento, CBOD was higher and PO_4 were lower than Base. At each of the three locations, there were clear shifts in the timing of concentration or in the width of peaks in comparison with the Base for algal biomass, nitrate and CBOD.

At Potato Point (Figure 17-101 through Figure 17-104), the comparisons with respect to the Base case were very similar to the trends at Point Sacramento.

In general, constituent concentration differences were substantial immediately downstream of the confluence of the Sacramento River and Cache Slough and decreased with distance. Within the

[15] Many thanks are extended to CH2MHill and DWR-DMS for releasing an early version of this grid and model input.

Yolo/Liberty/Cache Slough area, the changes in comparison with Base were even larger, so it is appears that the influence of the flooded Liberty Island could be substantial if modeled nutrient are considered in selecting areas for their potential restoration area.

Table 11-1 Volumetric fingerprinting source names.

Volume Source	Volumetric Output Name
Martinez Boundary	VOL-MTZ
Sacramento River	VOL-SAC
Yolo Bypass	VOL-YOLO
Toe Drain (2004 – 2008 only)	VOL- TOE
San Joaquin River	VOL-SJR
Calaveras River	VOL-CAL
Mokelumne River	VOL-EAST
Consumnes River	
Sac Regional WWTP	VOL-SACRWW
Stockton WWTP	VOL-STCKWW
Lodi WWTP	VOL-LODIWW
Manteca WWTP	VOL-MNTCAWW
Central Contra Costa WWTP	VOL-CCCSDWW
Delta Diablo WWTP	VOL-DDWW
Tracy WWTP	VOL-SDELWW
Discovery Bay WWTP	
Mountain House WWTP	
Fairfield-Suisun WWTP	VOL-MTZWW
Martinez Refinery+Tesoro	
Valero Refinery	

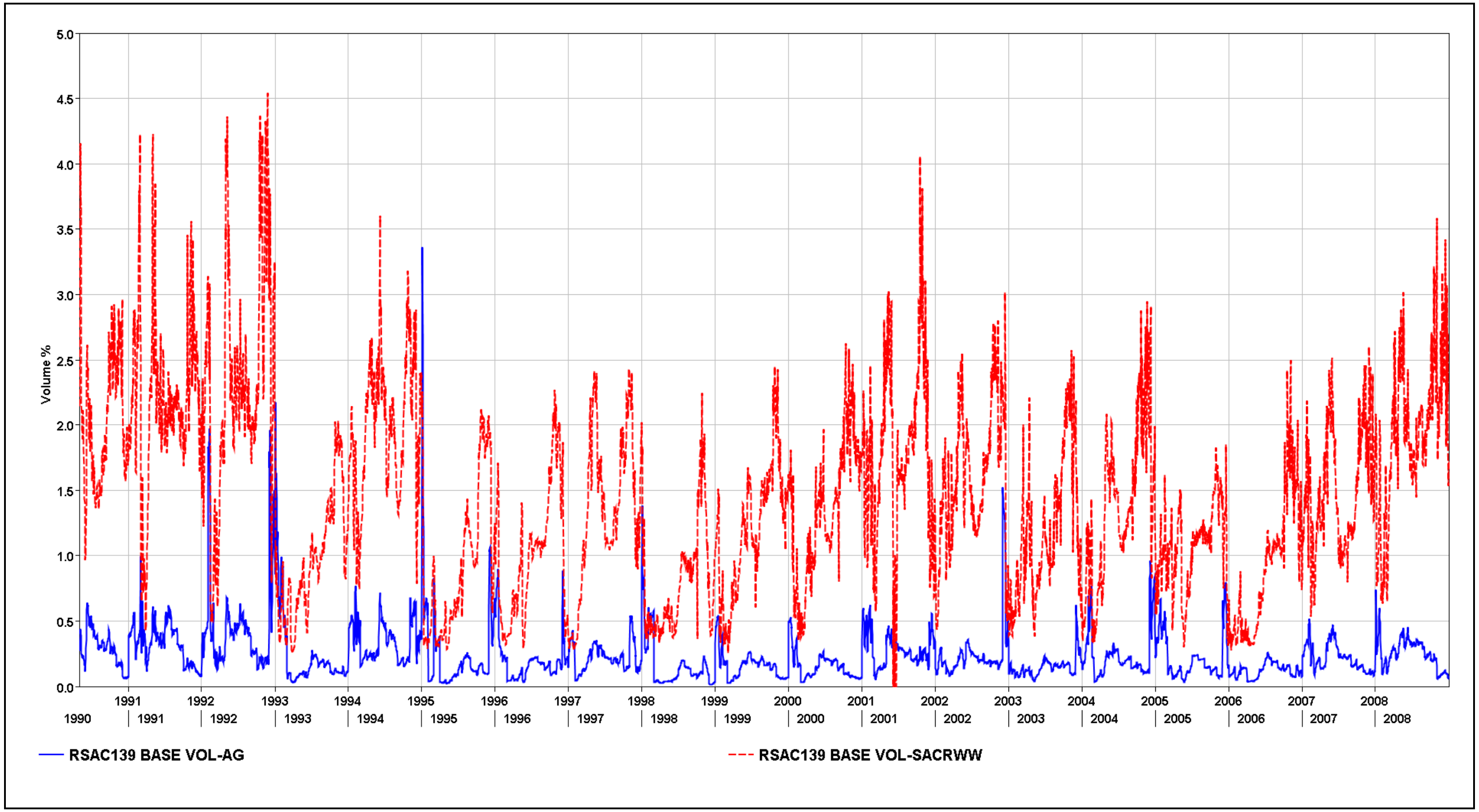


Figure 11-1 Ag and Sac Regional effluent volumes at Greene's Landing.

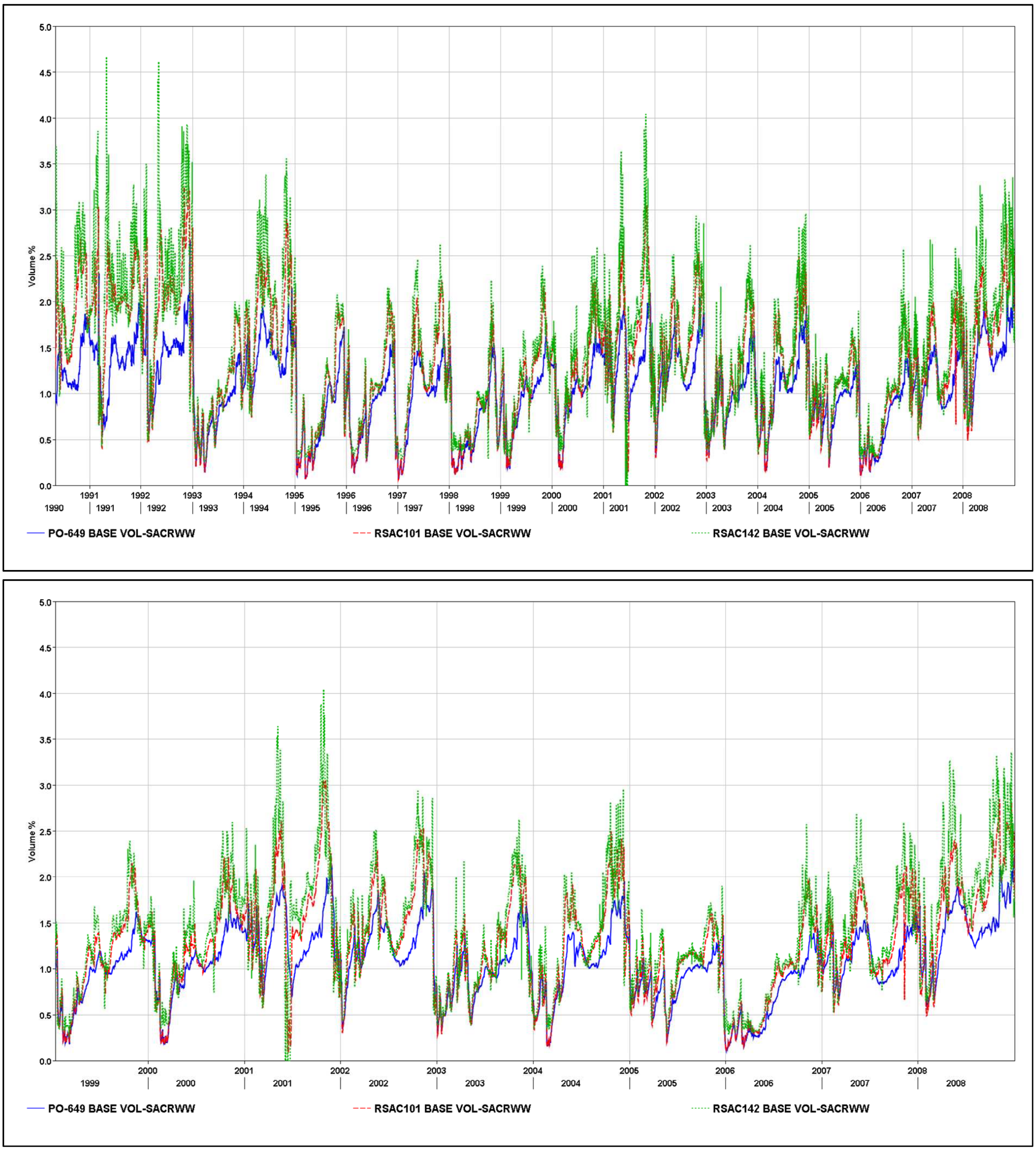


Figure 11-2 Sac Regional effluent volumes along the Sacramento River.

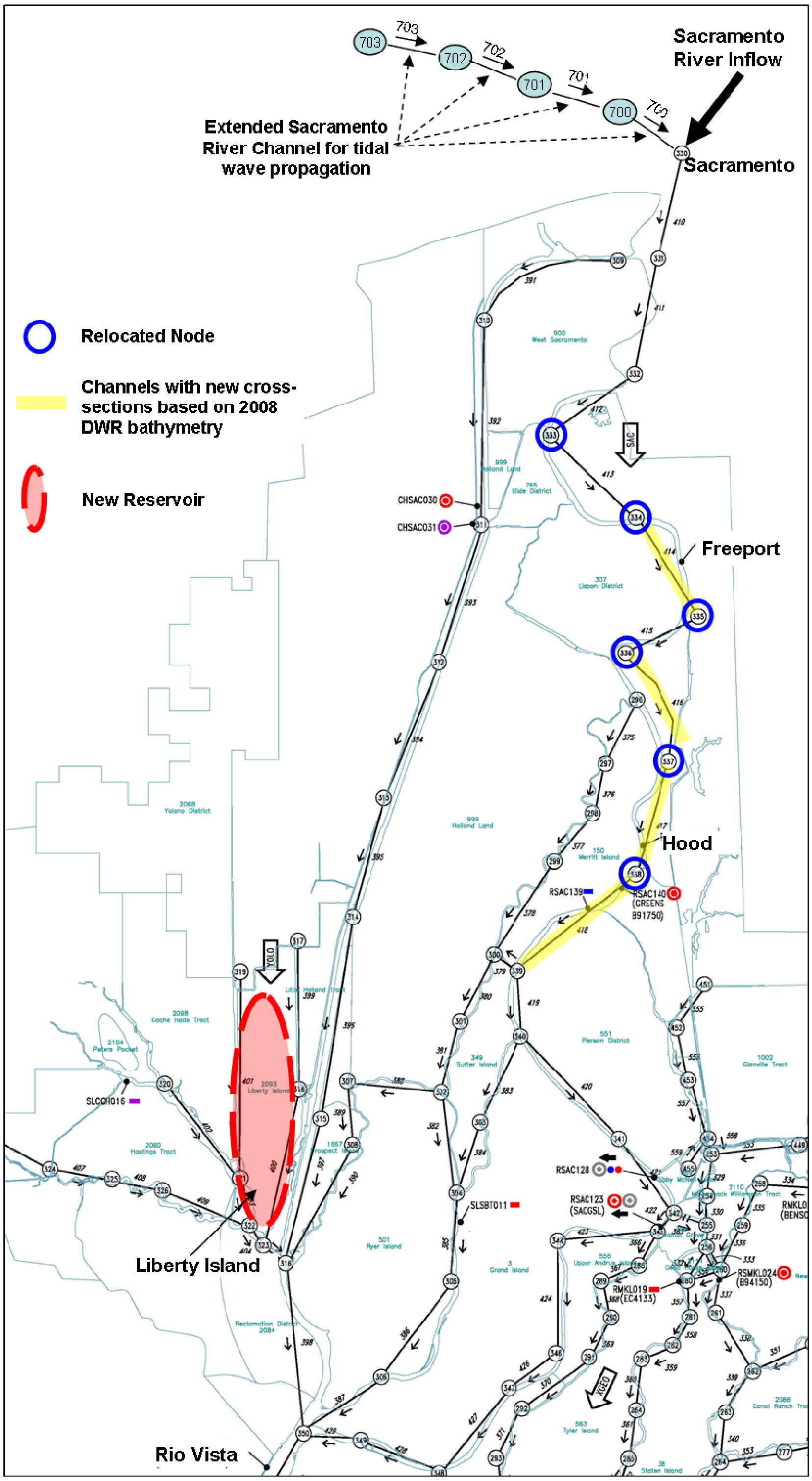


Figure 11-3 DSM2 grid alterations for the Liberty Island (red region) recalibration.

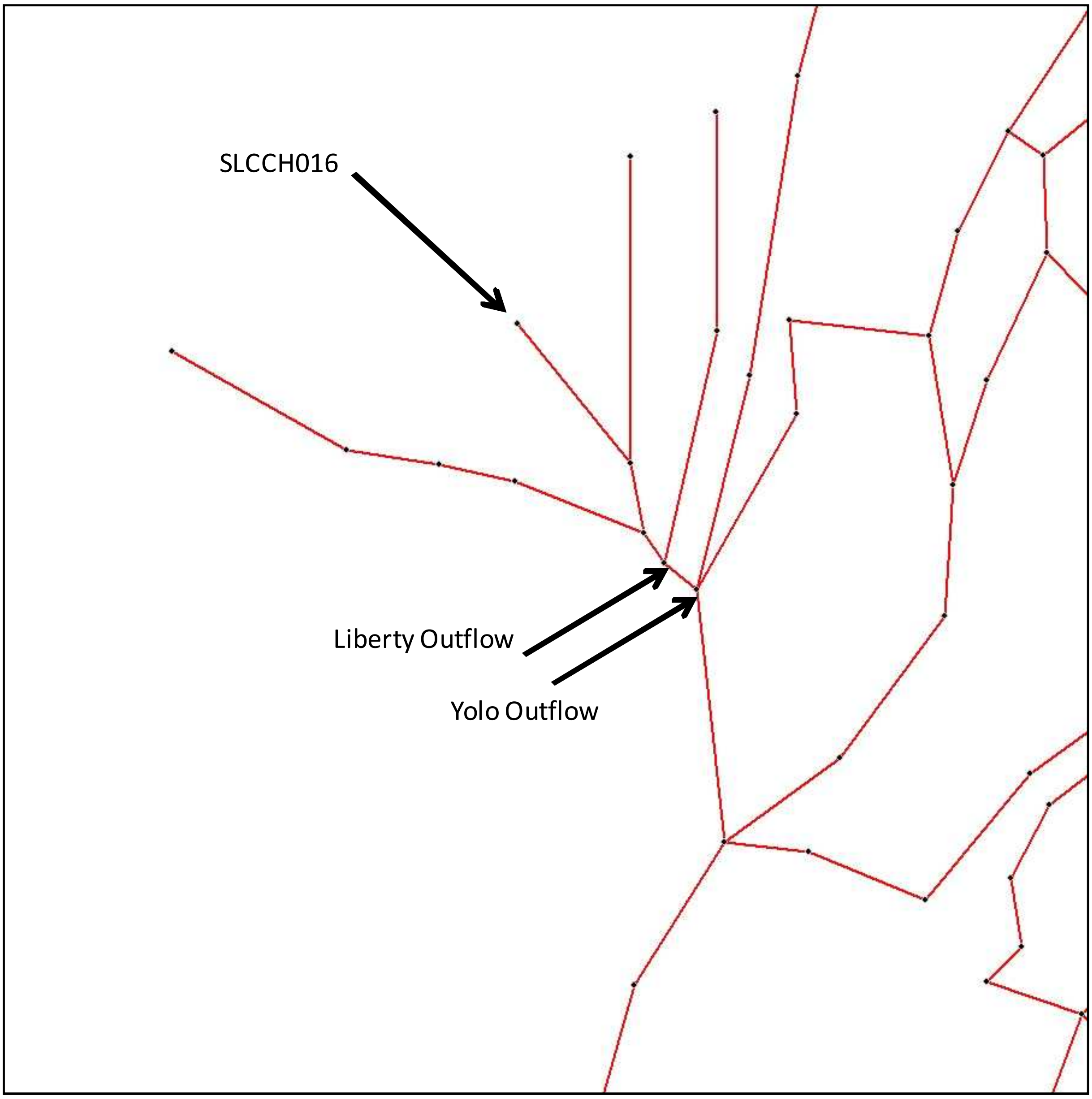


Figure 11-4 Three output locations in the DSM2 grid used to study the effects of a flooded Liberty Island.

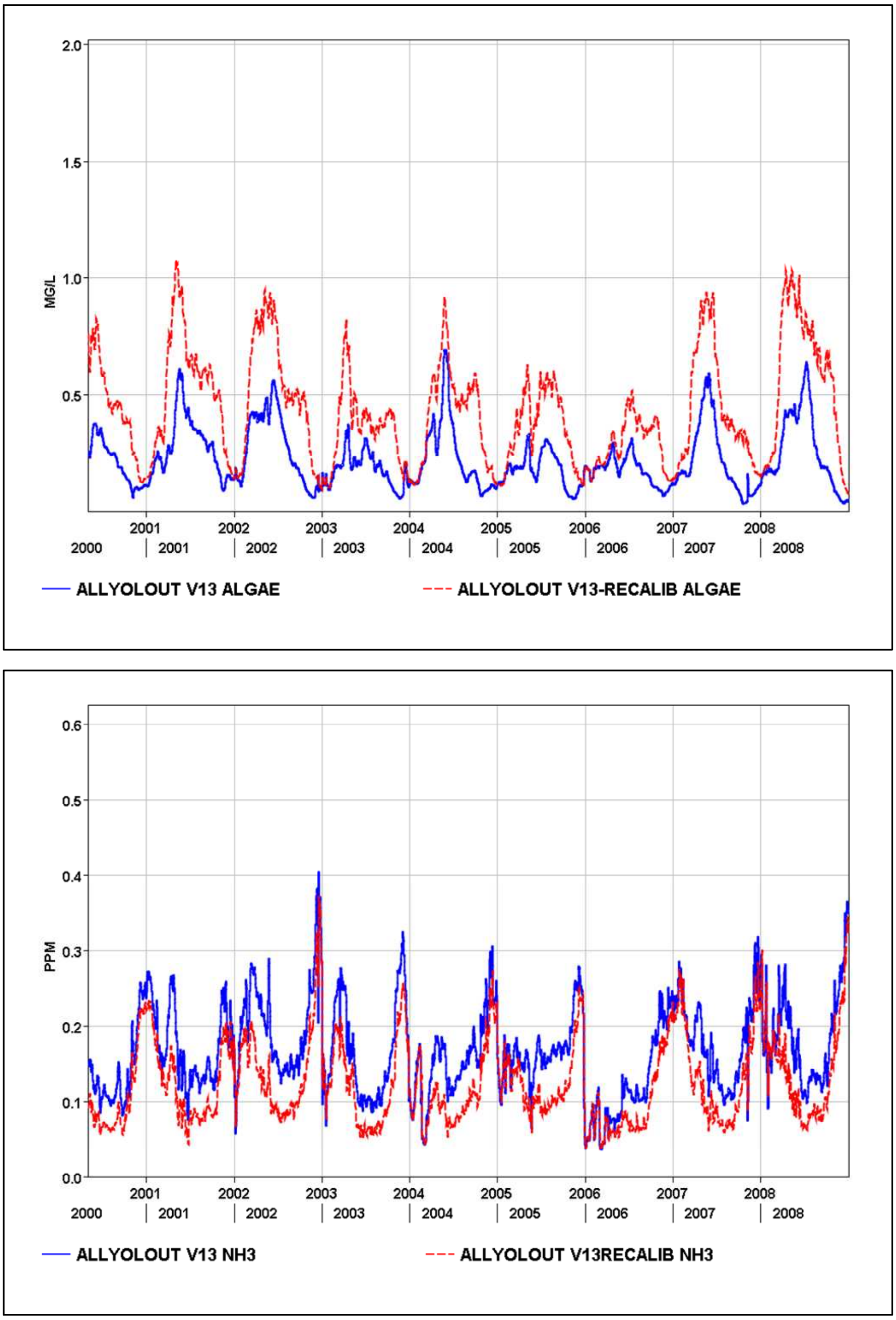
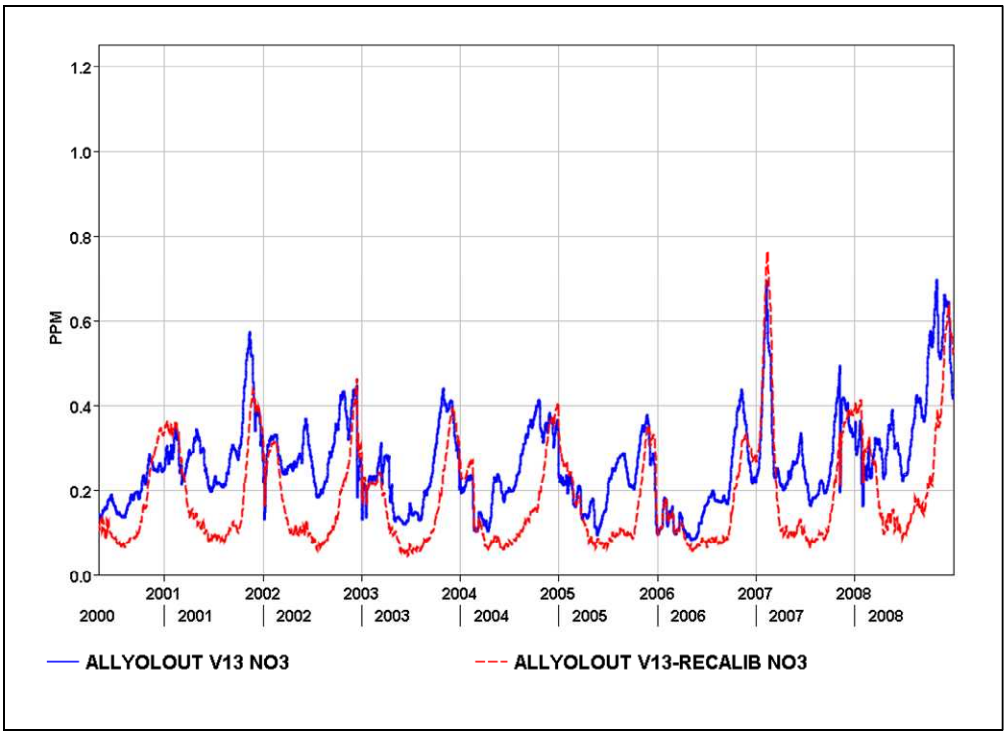


Figure 11-5 Algal biomass and ammonia concentrations at the Yolo location for Base and Liberty grids.



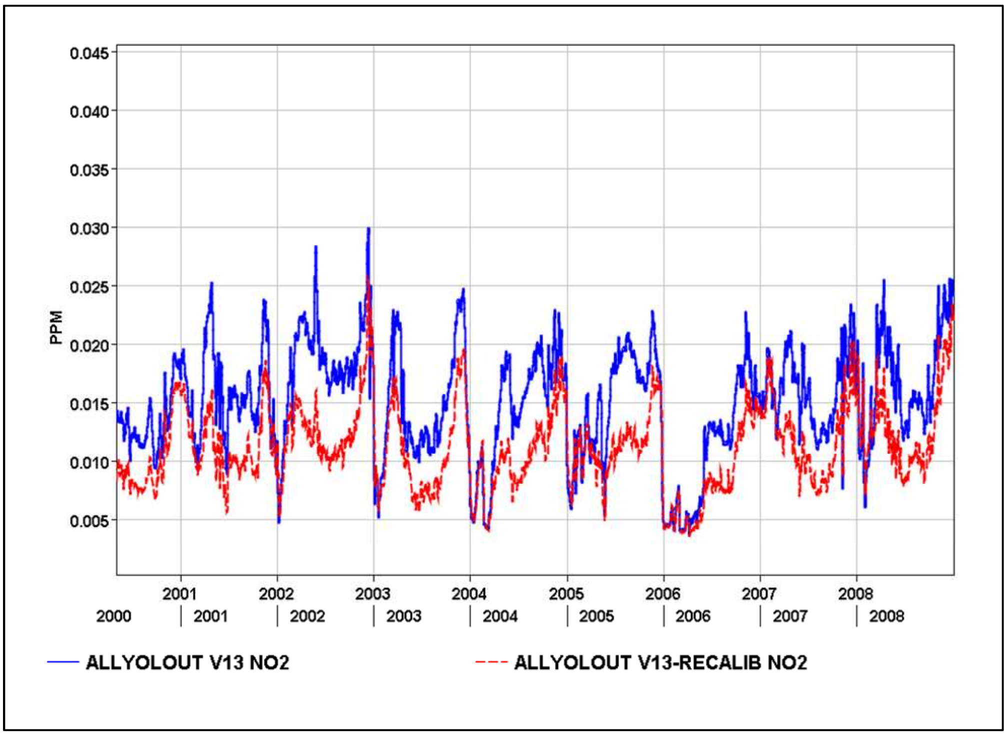
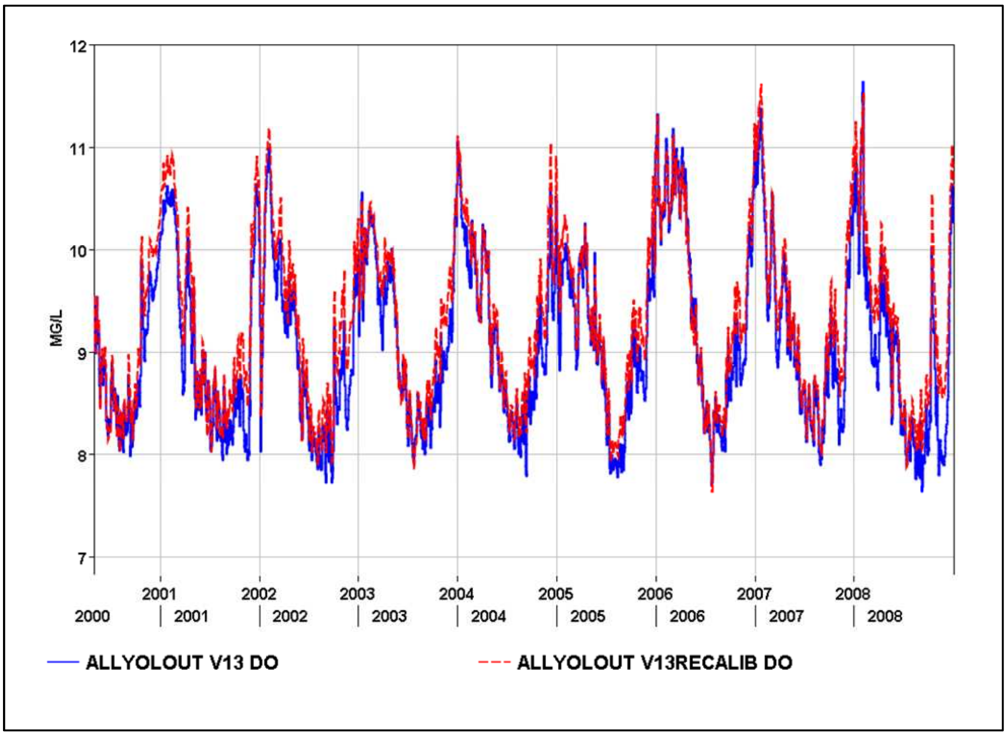


Figure 11-6 Nitrate and nitrite concentrations at the Yolo location for Base and Liberty grids.



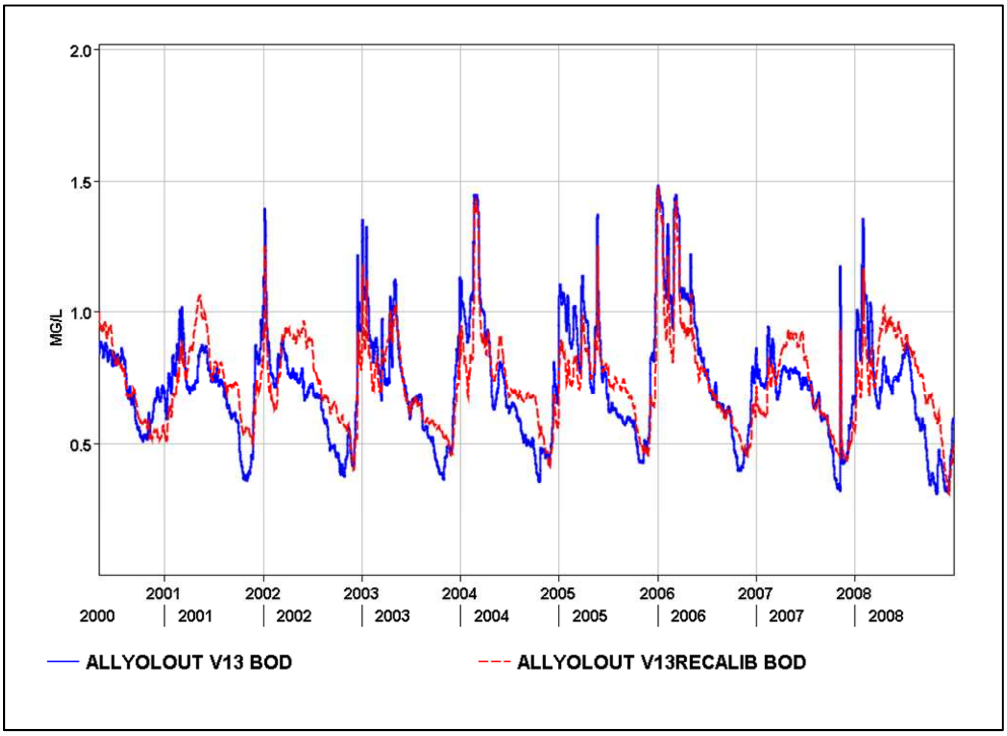


Figure 11-7 DO and CBOD concentrations at the Yolo location for Base and Liberty grids.

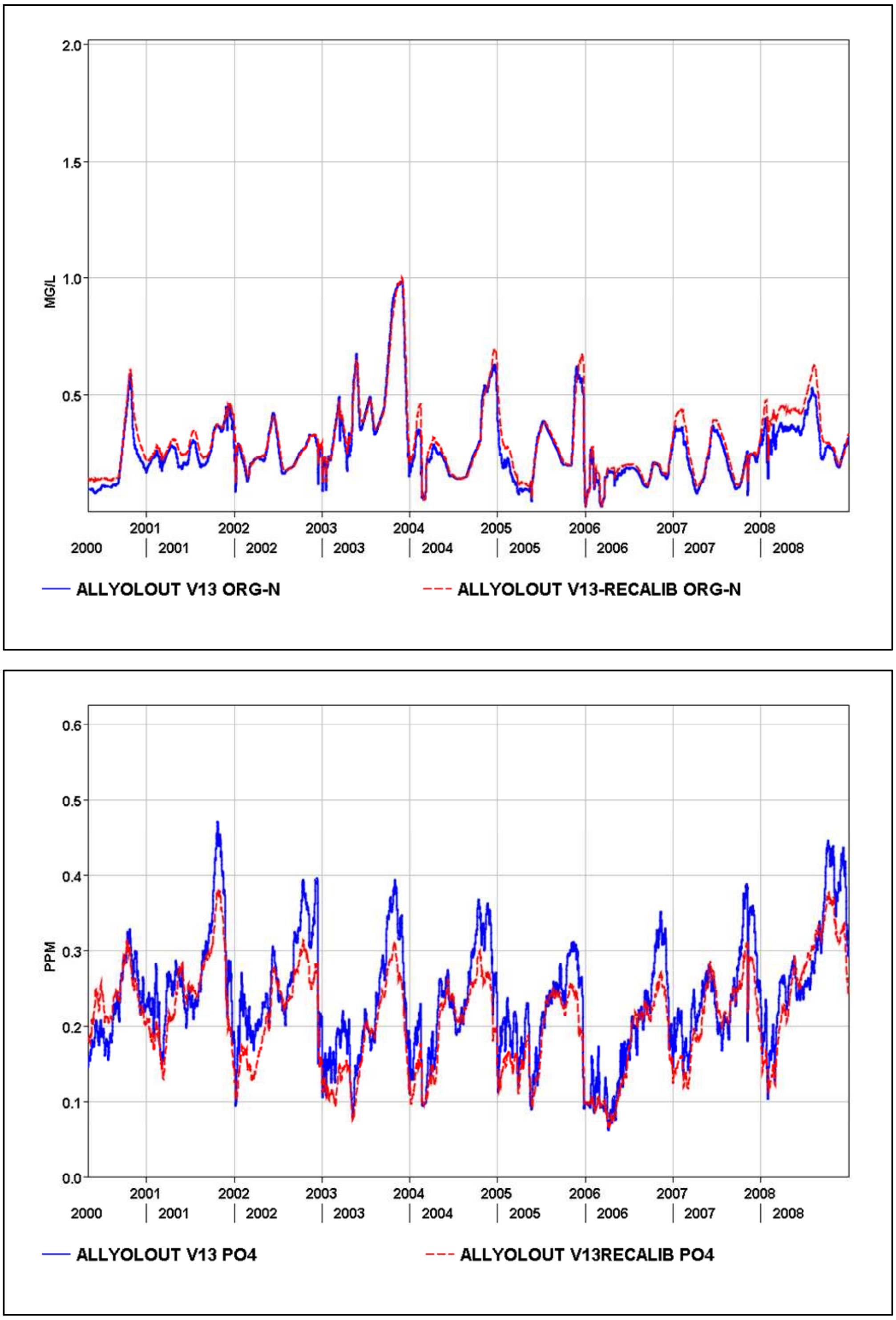
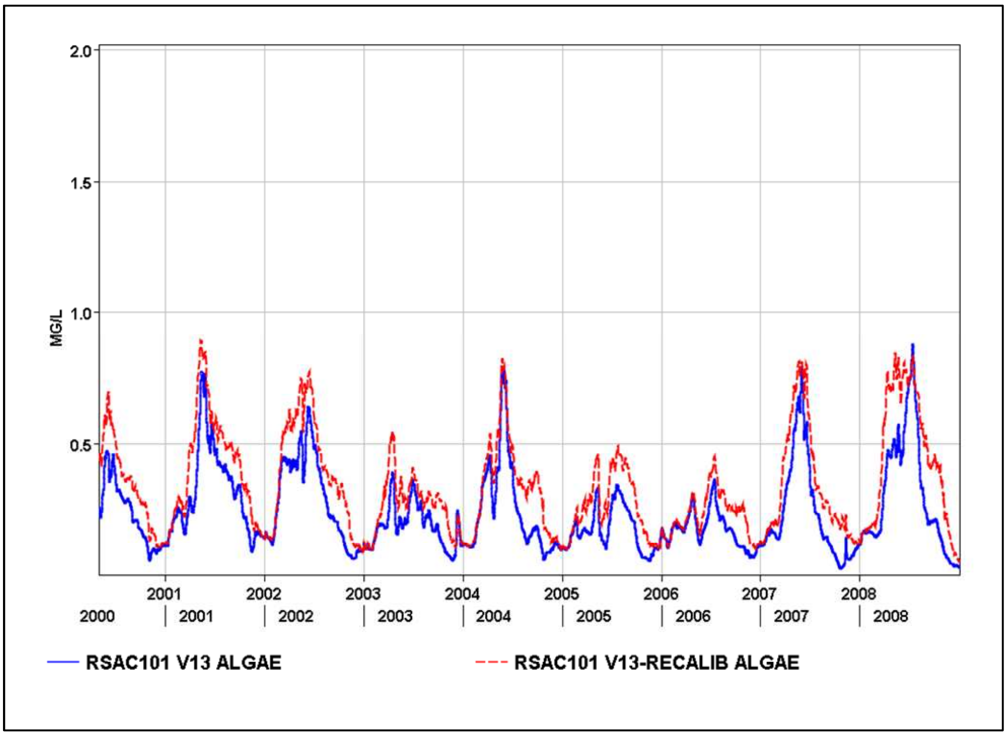


Figure 11-8 Organic-N and PO_4 concentrations at the Yolo location for Base and Liberty grids.



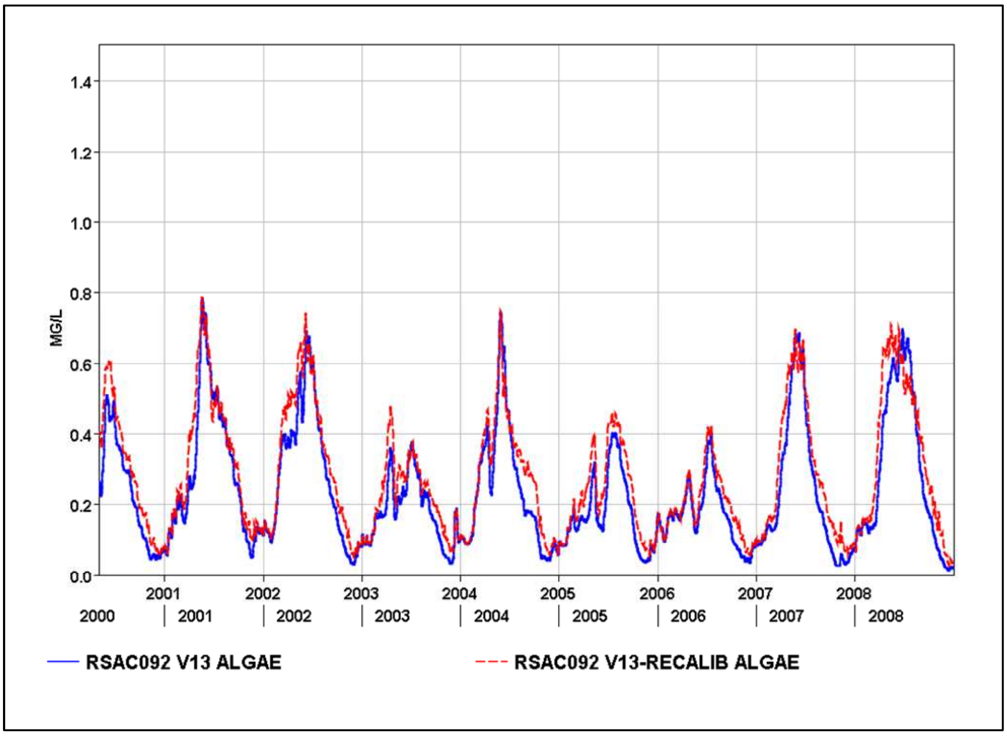
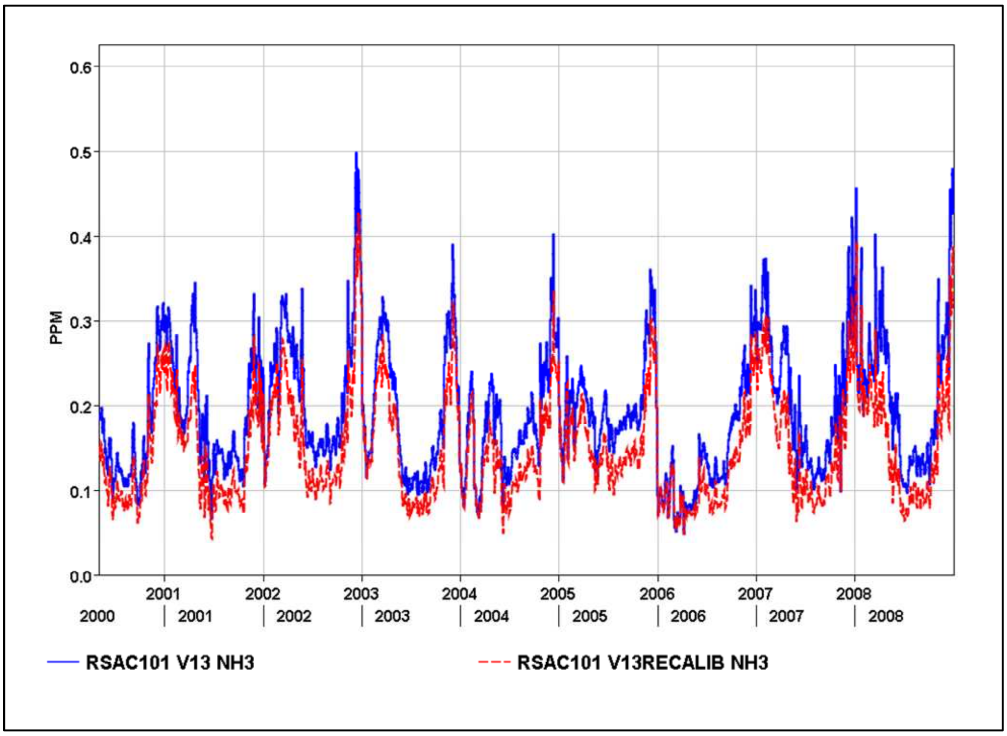


Figure 11-9Algal biomass at RSAC101 and RSAC092 for Base and Liberty grids.



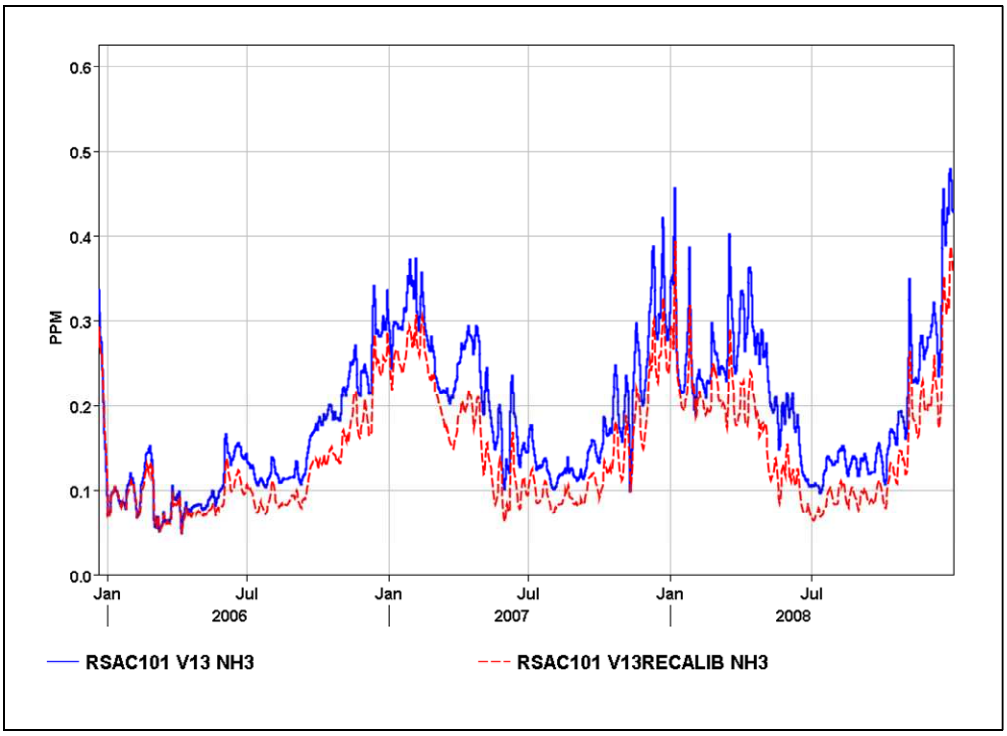
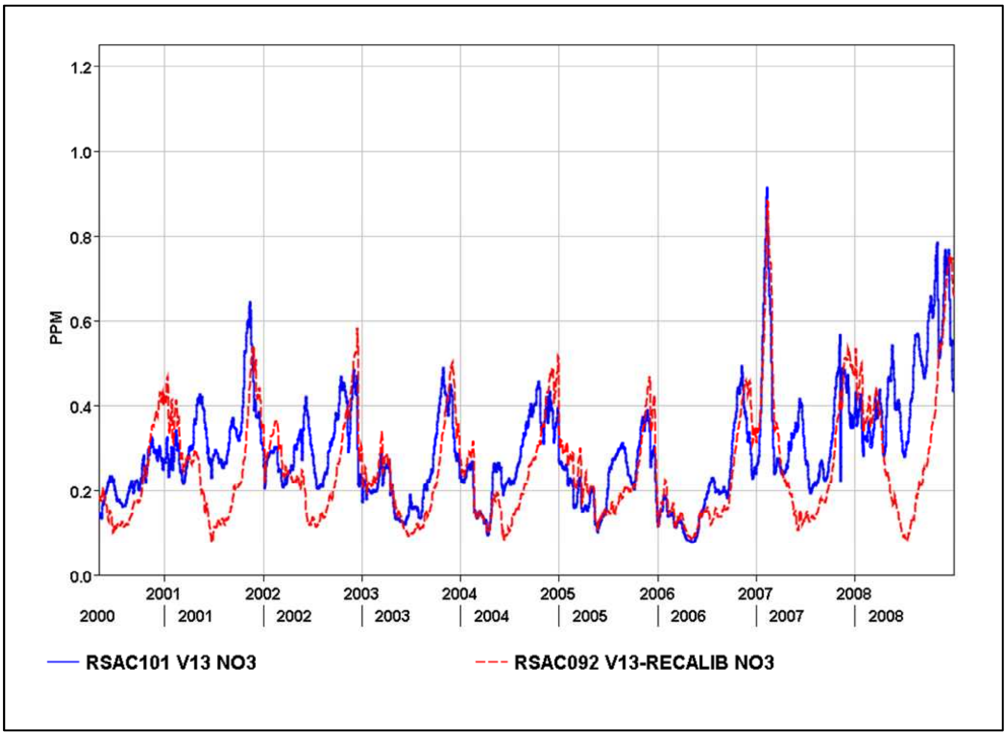


Figure 11-10 Ammonia at RSAC101 for Base and Liberty grids.



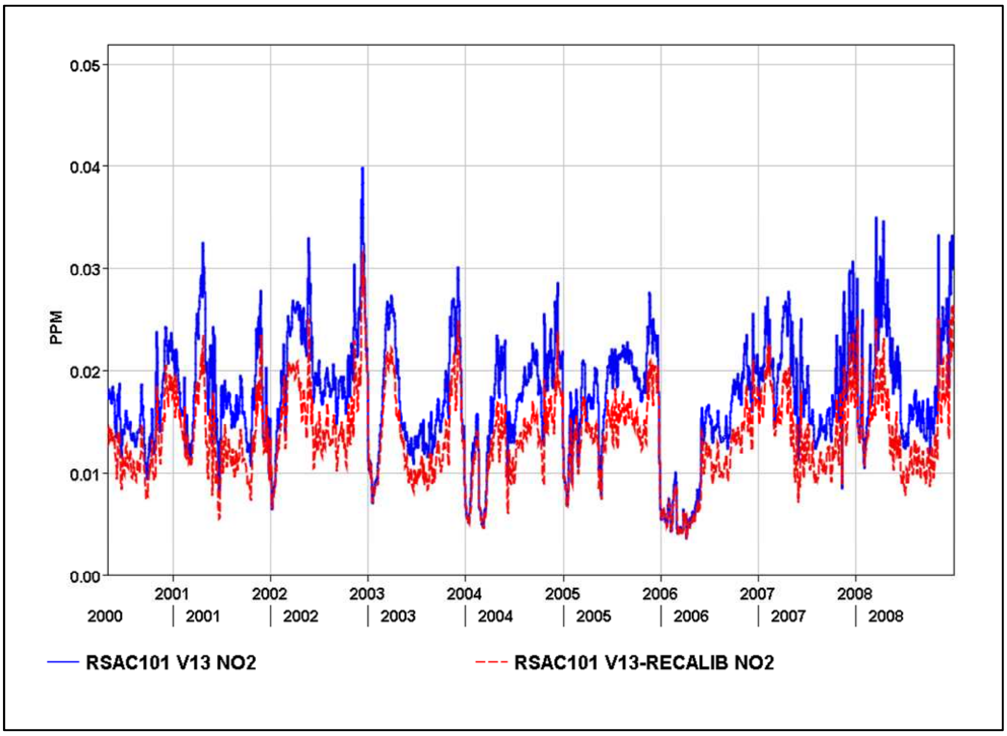


Figure 11-11 Nitrate and nitrite at RSAC101 for Base and Liberty grids.

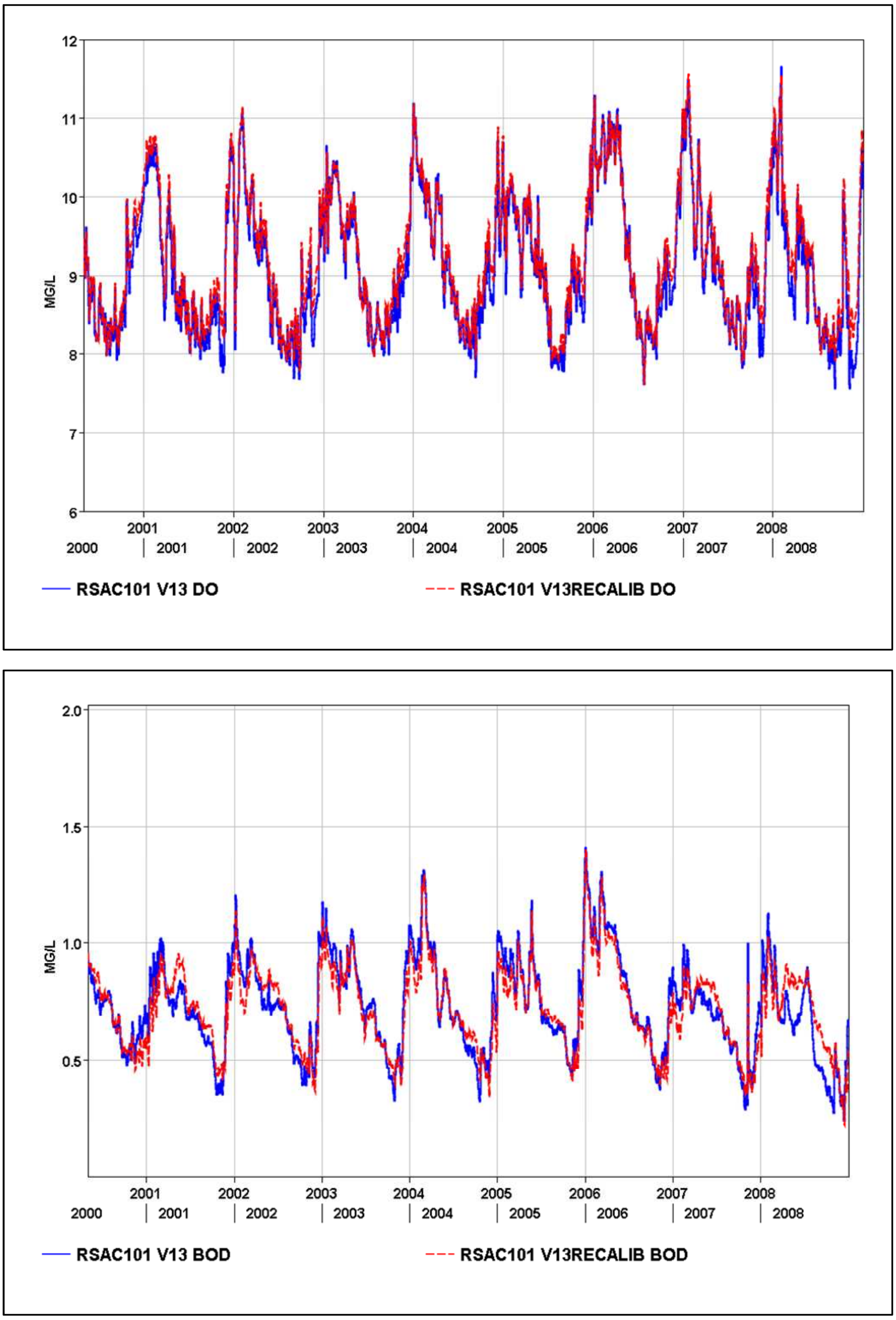


Figure 11-12 DO and CBOD at RSAC101 for Base and Liberty grids.

12 Scenarios – Sensitivity to Changes in N-concentrations

Model output locations described in the scenarios are documented in Figure 12-1 through Figure 12-4. Not all locations have corresponding figures in the text below. Results are summarized as monthly percent change from Base in each section. Figures illustrating results are found at the end of this section, and also in Appendix I Section 17.11. These analyses generally changed the concentration of all of the N-constituents by +/- 20%, except where noted.

Boundary conditions for all constituents, including N-constituents, were set as hourly, daily, monthly or constant inputs during model development. The choice was dictated for each constituent by data availability, magnitude of constituent concentration and the sensitivity of the model calculations to changes in timing and magnitude. The sensitivity results below test the response of the model to changes in the suite of N-constituents.

12.1 Increase/decrease DICU N-constituents

To test the sensitivity of model results to changes in N-constituent concentrations at the DICU boundaries, two scenarios were run in which the constant NO_3, NO_2, NH_3 and organic-N boundary concentrations were increased and decreased by 20%.

Changes in nutrient concentrations due to changes in DICU boundary condition concentrations were extremely small along the Sacramento River corridor and in the north Delta, and nearly undetectable in general on a monthly-averaged basis. This is illustrated in Figure 17-105 and Figure 17-106. Nitrate changes were the largest – there were small changes (increases and decreases) in PO_4 and DO in response to nutrient dynamics due to changes in N-constituents. Results are summarized as average percent change from Base.

During dry periods in comparison with the Historical model, the effects were noticeable but small along the San Joaquin River, mainly upstream of Antioch (Figure 17-107). Changes in ammonia and nitrate increased somewhat at upstream locations (Figure 17-108 through Figure 17-111). Changes are most noticeable where DICU flow contributions are greatest, mainly in periods of low boundary inflow during Dry and Critically Dry water years.

Average monthly percent change from Base Historical model (+/- 20% change)

	Algae	NH3	NO3	NO2	Org-N	PO_4/DO
Inc DICU-N						
RSAC101	+ 1 – 4 %	+ 1 – 4 %	+ 3 – 7 %	+ 1 – 4 %	0 %	+/+and-
RSAN037	+ 0 – 3 %	+ 2 – 6 %	+ 2 – 6 %	+ 2 – 6 %	+ 0 %	+and-/+and -
RSAN018	+ 2 – 7 %	+ 3 – 8 %	+ 3 – 6 %	+ 3 – 8 %	0 %	+/+and-
Dec DICU-N						
RSAC101	- (0 – 3) %	- (0 – 1) %	- (0 – 1) %	- (0 – 1) %	0 %	+/+
RSAN037	- (0 – 3) %	- (2 – 6) %	- (2 – 5) %	- (2 – 6) %	- 0 %	+and -/+and -
RSAN018	- (0 – 3) %	- (1 – 4) %	- (1 – 3) %	- (1 – 4) %	0 %	+/+and-

12.2 Increase/decrease N-constituents at the Sacramento Boundary

To test the sensitivity of model results to changes in N-constituent concentrations at the Sacramento R. boundary, scenarios were run in which NO_3, NO_2, NH_3 and organic-N concentrations were increased and decreased by 20%. NO_2 concentration was not changed as it was very low and constant. Results are summarized as percent change from Base below for three downstream locations.

At Isleton on the upstream end of the Sacramento R., no changes were seen in algae dynamics (Figure 17-112) – these also held true for downstream locations (Figure 17-113). For N-constituents, changes were moderate and largest for nitrate (Figure 17-114 through Figure 17-116). Similar results were seen at Georgiana Slough (Figure 12-5 and Figure 12-6). Nitrite concentration changes were largest in drier years, while nitrate concentrations were largest in wetter years indicating that decay into nitrite and algal consumption of nitrate were noticeably concentration and temperature-dependent. Changes in organic-N persisted downstream, as the boundary contributes most of the organic-N along the Sacramento corridor.

Changes at Potato Point were still quite noticeable (Figure 12-7 through Figure 12-9). They decreased for ammonia and nitrite at Antioch, but still remained quite noticeable for nitrate (Figure 17-117 through Figure 17-119). Nitrite changes are due to decay of ammonia. There were essentially no changes in PO_4 and DO. Differences between drier and wetter year types were greatest for nitrate.

Average monthly percent change from Base Historical model (+/- 20% change)

	Algae	**NH3**	**NO3**	**NO2**	**Org-N**
Inc Sac River-N					
RSAC101	+ 0 – 2 %	+ 3 – 6 %	+ 9 – 15 %	+ 3 – 6 %	+ 16 – 18 %
PO649	+ 0 – 6 %	+ 3 – 6 %	+ 7 – 12 %	+ 3 – 6 %	+ 14 – 17 %
RSAN018	+ 0 – 7 %	+ 3 – 5 %	+ 6 – 9 %	+ 3 – 5 %	+ 11 – 16 %
Dec Sac River-N					
RSAC101	- (0 – 2) %	- (4 – 6) %	- (9 – 14) %	- (3 – 6) %	- (16 – 18) %
PO649	- (0 – 6) %	- (3 – 6) %	- (7 – 12) %	- (3 – 6) %	- (14 – 17) %
RSAN018	- (0 – 7) %	- (3 – 5) %	- (6 – 9) %	- (3 – 5) %	- (11 – 16) %

12.3 Increase/decrease N-constituents at the San Joaquin Boundary

To test the sensitivity of model results to changes in N-constituent concentration at the San Joaquin R. boundary, two scenarios were run in which NO_3, NH_3 and organic-N were each increased and decreased by 20%. NO_2 concentration was not changed to maintain similarity with Sacramento R. boundary changes.

Concentration changes were relatively minor except for changes in NO_3. Nitrate concentrations are variable on the SJR past Jersey Point (RSAN018) during higher SJR flow conditions. This is illustrated in Figure 12-10, Figure 17-120 and Figure 17-121. Results are summarized below as percent change from Base for two downstream locations.

Average monthly percent change from Base Historical model (+/- 20% change)

	Algae	NH3	NO3	NO2	Org-N	PO_4/DO
Inc SJR-N						
RSAN037	+ 0 - 1 %	+ 0 – 4 %	+ 0 – 16 %	+ 0 – 4 %	+ 0 – 12 %	+and-/+and-
RSAN018	+ 0 – 3 %	+ 0 – 2 %	+ 0 – 9 %	+ 0 – 1 %	+ 0 - 5 %	+and-/+and-
Dec SJR-N						
RSAN037	- (0 – 2) %	- (0 - 4) %	- (1 - 16) %	- (0 - 4)%	- (0 - 12) %	+and-/+
RSAN018	- (0 - 3) %	- (0 - 2) %	- (0 - 9) %	- (0 - 2) %	- (0 - 5) %	+/+and-

12.4 Increase/decrease N-constituents in Sac Regional Effluent

To test the sensitivity of model results to changes in N-constituent concentration at the Sac Regional WWTP effluent boundary, two scenarios were run in which NO_3, NO_2, NH_3, and organic-N were each increased and decreased by 20%. Results are summarized as percent change from Base below for three downstream locations.

The changes in N-constituent concentration downstream of the Sac Regional WWTP were large and sustained along the Sacramento R. corridor to Suisun Bay. Ammonia and nitrite concentrations showed the largest shifts – nitrite is produced as ammonia decays. Changes in the dynamics of the other constituents, organic-N, chl-a/algae and DO, were minor and sporadic, but also extended down to Suisun Bay in periods where there were detectable changes in concentration. There was essentially no change in the concentration of PO_4.

The changes in constituent concentrations along the Sacramento R. from Isleton to Suisun Nichols are documented in Figure 12-11 through Figure 12-15 and Figure 17-122 through Figure 17-131. Small increases in algal growth with increased effluent N-concentrations appear with increasing distance from the Sac Regional outfall along the Sacramento R. main stem. Decreases in effluent-N resulted in small decreases of algal growth. Changes in constituent concentrations are seen at other locations receiving Sac Regional wastewater- Jersey Point (Figure 17-126 and Figure 17-127), Georgiana Slough (Figure 17-128 and Figure 17-129), and at Potato Point (Figure 17-130 and Figure 17-131). Results are summarized below for three downstream locations.

Organic-N changes are small, as contributions are dilute in comparison with the Sacramento boundary inputs. Changes were most extreme during drier years for algae, ammonia and nitrate.

Average monthly percent change from Base Historical model (+/- 20 % change)

	Algae	**NH3**	**NO3**	**NO2**	**Org-N**
Inc SRWWTP-N					
RSAC101	+ 0 – 2 %	+ 13 – 16 %	+ 2 – 11 %	+ 12 – 16 %	+ 1 – 4 %
PO649	+ 0 – 7 %	+ 9 – 13 %	+ 4 – 12 %	+ 9 – 13 %	+ 1 – 4 %
RSAN018	+ 0 – 9 %	+ 9 – 13 %	+ 4 – 11 %	+ 9 – 13 %	+ 1 – 4 %
Dec SRWWTP-N					
RSAC101	- (0 – 3) %	- (14 – 16) %	- (3 – 11) %	- (12 – 16) %	- (1 – 4) %
PO649	- (0 – 8) %	- (9 – 13) %	- (4 – 11) %	- (9 – 13) %	- (2 – 4) %
RSAN018	- (0 – 10) %	- (8 – 13) %	- (4 – 11) %	- (9 – 14) %	- (1 – 4) %

12.5 Increase/decrease Sac Regional Effluent Volume

To test the sensitivity of model results to changes in N-constituent concentration at the Sac Regional WWTP effluent boundary, the volume of effluent was increased and decreased by 20%. The results for N-constituent concentration were for all practical purposes indistinguishable from the +/- 20% change in N-constituent concentration (Section 12.4), so results are not included here.

12.6 Increase/decrease N-constituents at Stockton WWTP Boundary

To test the sensitivity of model results to changes in N-constituent concentration at the Stockton WWTP effluent boundary, two scenarios were run in which NO_3, NO_2, NH_3, and organic-N were each increased and decreased by 20%.

The results show that the changes to N-constituent concentration, DO and algae are minor along the San Joaquin River downstream of the WWTP, and do not extend past Twitchell (RSAN024) in any appreciable amount (Figure 12-16, Figure 12-17, and Figure 17-132 through Figure 17-134). Results are summarized below for two downstream locations.

Average monthly percent change from Base Historical model (+/- 20% change)

	Algae	**NH3**	**NO3**	**NO2**	**Org-N**	**PO_4/DO**
Inc Stockton-N						
RSAN037	+ 0 %	+ 0 – 4 %	+ 0 – 3 %	+ 0 – 4 %	+ 0 – 2 %	+/-
RSAN018	+ 0 – 1 %	+ 0 – 1 %	+ 0 – 2 %	+ 0 – 1 %	+ 0 - 1 %	+and-/+and-
Dec Stockton-N						
RSAN037	- 0 %	- (0 - 4) %	- (0 - 3) %	- (0 - 4)%	- (0 - 2) %	+/+
RSAN018	- (0 - 3) %	- (0 - 2) %	- (0 - 9) %	- (0 - 2) %	- (0 - 5) %	+/+and-

12.7 Summary of Sensitivity Scenarios

Generally, increases and decreases in N-constituent concentrations were mirrored in percent change in monthly concentrations - i.e., increases and decreases were generally of the same magnitude within 1 – 2 %, the only difference being the difference in sign. The two exceptions to this are the DICU and Stockton WWTP scenarios – in these cases, during periods of low flow the nutrient dynamics were no longer symmetric (positive and negative different).

As the N-constituents were all varied at once, it is difficult to separate out specific effects. Downstream of the Sacramento and San Joaquin boundaries, nitrification was evident in the change in nitrite concentration as that N-constituent wasn't varied. In general, increasing N-constituents resulted in increased algal biomass, while decreases resulted in a decrease in algal biomass.

12.8 Modify Sac Regional WWTP Process for Nitrification

A scenario was developed to test the downstream consequences for Delta nutrient dynamics of a change to a nitrification wastewater treatment process at SAC Regional WWTP. Stockton and Tracy WWTPs had each switched their treatment processes to nitrification, so the changes in their effluent concentrations were used as a guide to develop a reasonable set of effluent conditions. In both plants, the changes to CBOD, NO_3, NH_3, and organic-N were each quite substantial.

For the scenario, the original Sac Regional effluent flows were maintained and only constituent concentrations were changed. The NH_3 concentrations were decreased by a factor of 0.04, the NO_3, concentrations were increased by a factor of 15, the organic-N concentrations were cut in half, and the CBOD concentration was multiplied by a factor of 0.23.

The results for this scenario present a much more complicated picture of the dynamics resulting from the change in the effluent boundary. As expected, there is a large decrease in ammonia – there is also a substantial increase in nitrate concentrations at all downstream locations. There is a relatively small increase in DO and a decrease in algal biomass, with a few exceptions where biomass may increase for a year or two (Figure 17-141 and Figure 17-144). Nitrite shows large decreases at all locations which are apparently linked to the ammonia decrease as decay is no longer a factor in nitrite production. The decrease in organic-N is minor.

In some cases, there is a shift in the timing of high points and low points in concentration (e.g., Figure 17-136 and Figure 17-148) particularly for nitrate. Algal biomass is nearly unchanged at some locations during Wet water years (Figure 17-141).

Results are summarized below (Table 12-1 through

Table 12-7) for two downstream locations. Changes from Base are largest and smallest during the summer months. Bold font indicates which months and year types have the most extreme results. For example, the ammonia section of Table 12-1 for RSAC101 shows that the summer months (July – September) operate under a different nutrient regime than the other months. In these months, the average for the Dry+Critical years.

12.9 Clams (Corbula and Corbicula)

Attempts to modify model parameters to mimic the change in nutrient dynamics due to clams, generally through increased nutrient consumption (including consumption of algae) were unsuccessful. The main parameters that could be varied were algal growth and death rates. Increases or decreases in constituent concentrations associated with the dynamics of their life cycle, for example an increase in the production of benthic NH_3 to mimic excretion, were difficult to quantify in the literature examined.

The change in consumption of nutrients due to consumption by clams needed to be variable in time and tied to other parameters. *Corbula* and *Corbicula* do not necessarily consume nutrients year-round, and their growth and maturation cycles depend on having the correct conditions for salinity and water temperature, for example. *Corbula* (J. Thompson, PowerPoint available on web[16]) recruits prefer more saline conditions, settling downstream of X2[17] so generally do not appear in great numbers past Collinsville. Historically, *Corbula* has invaded the greatest proportion of the Delta during low outflow conditions leading to their expansion into formally fresher water areas. *Corbicula* favors fresher water environments, and juveniles generally settle upstream of X2.

Implementing changes in algal growth and death rates tended to change both the increasing and decreasing arms of the annual growth curves. The result would be peaks that might have the correct integrated area for a season, but that would miss the timing and pattern of increasing and declining growth. Figure 12-24 shows potential habitat for the two clams. Model results for algae tended to indicate that algal growth peaks were cut in areas where clam biomass measurements have been high historically.

[16] http://science.calwater.ca.gov/pdf/workshops/workshop_dcm2_presentation_Thompson.pdf

[17] X2 is the distance in km from the Golden Gate Bridge to the 2 psu bottom salinity location

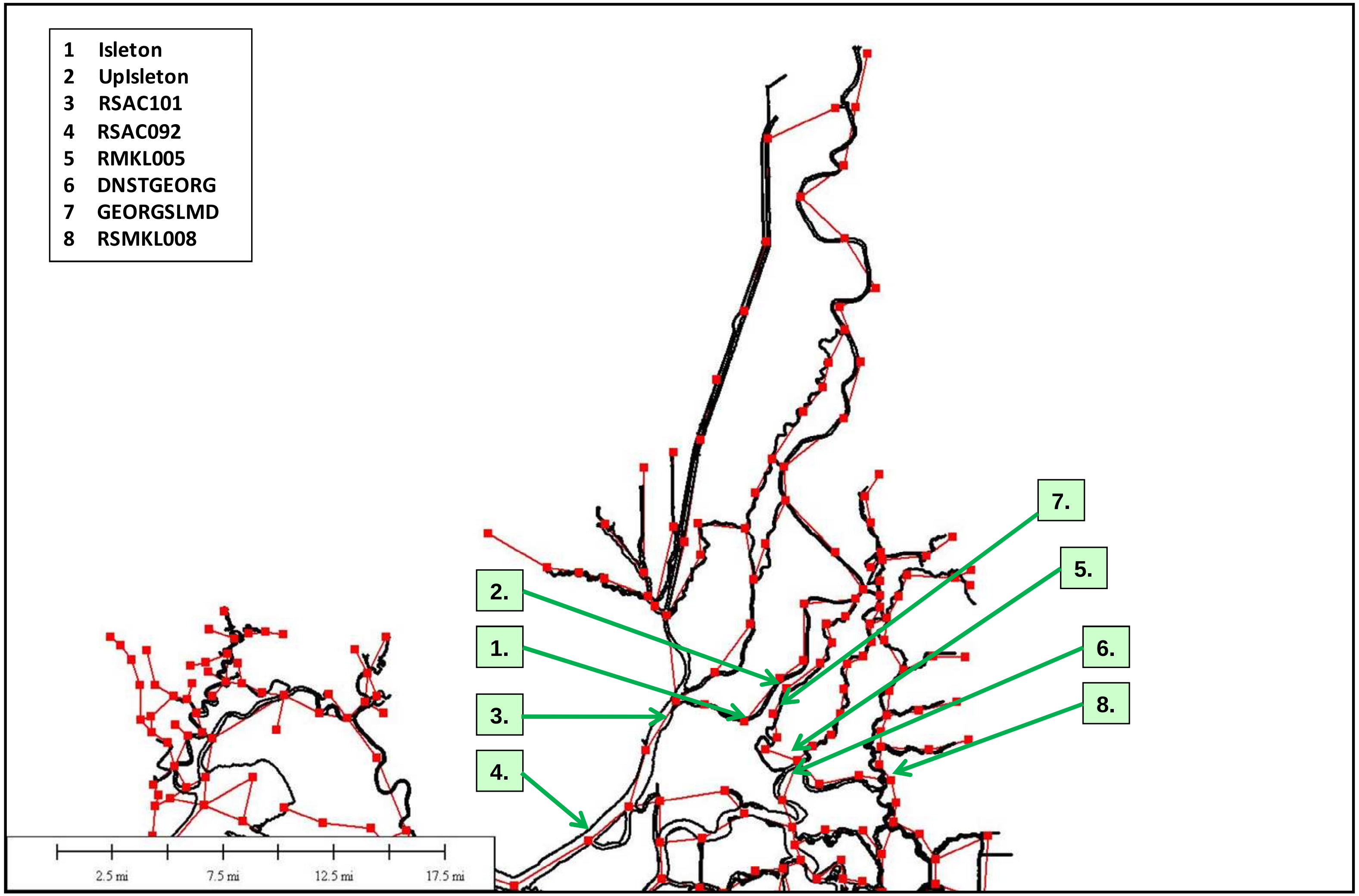


Figure 12-1 Model output locations in the northern Delta for the scenarios.

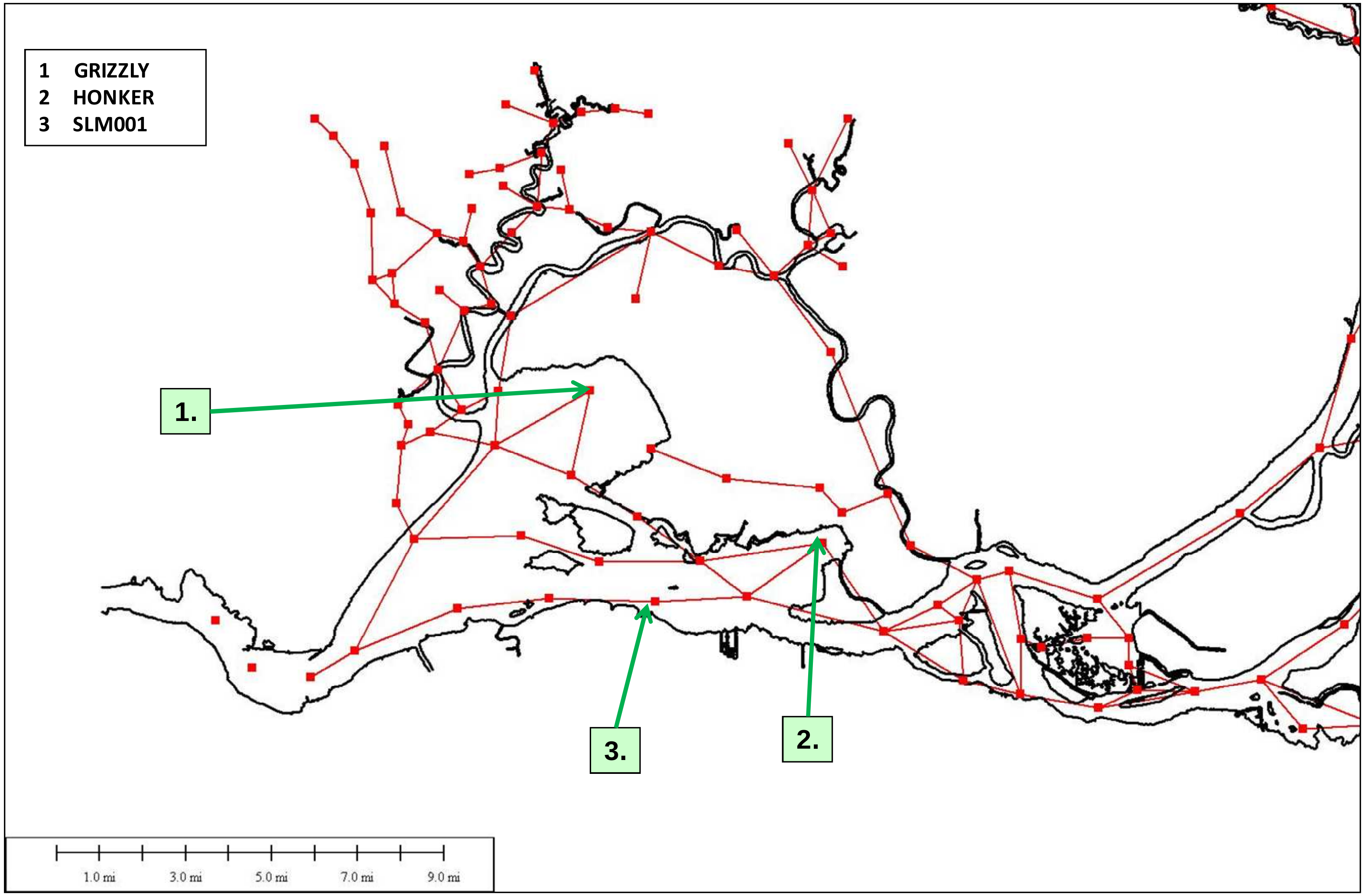


Figure 12-2 Model output locations in the western Delta for the scenarios.

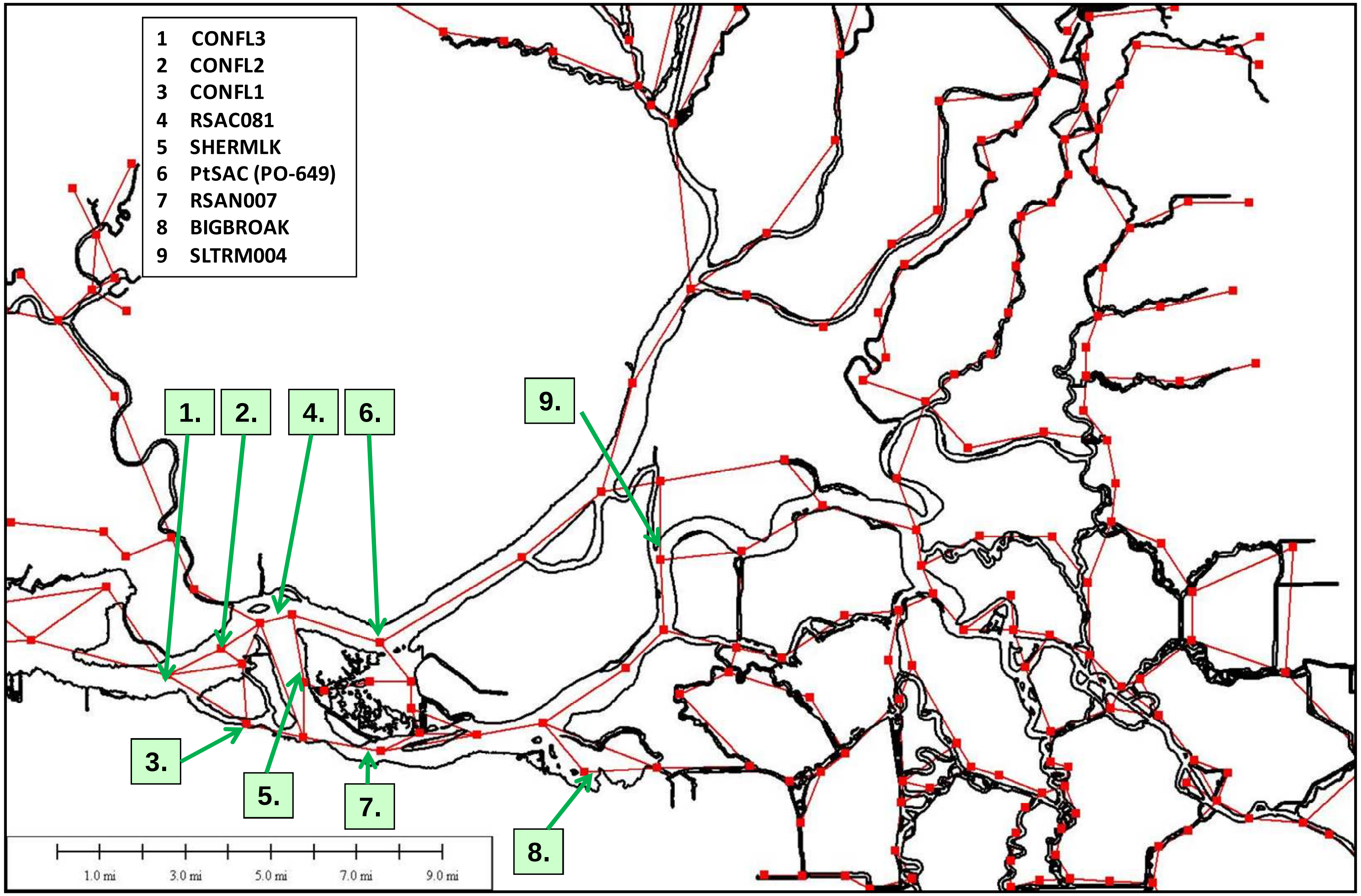


Figure 12-3 Model output locations near the confluence of the Sacramento and San Joaquin Rivers for the scenarios.

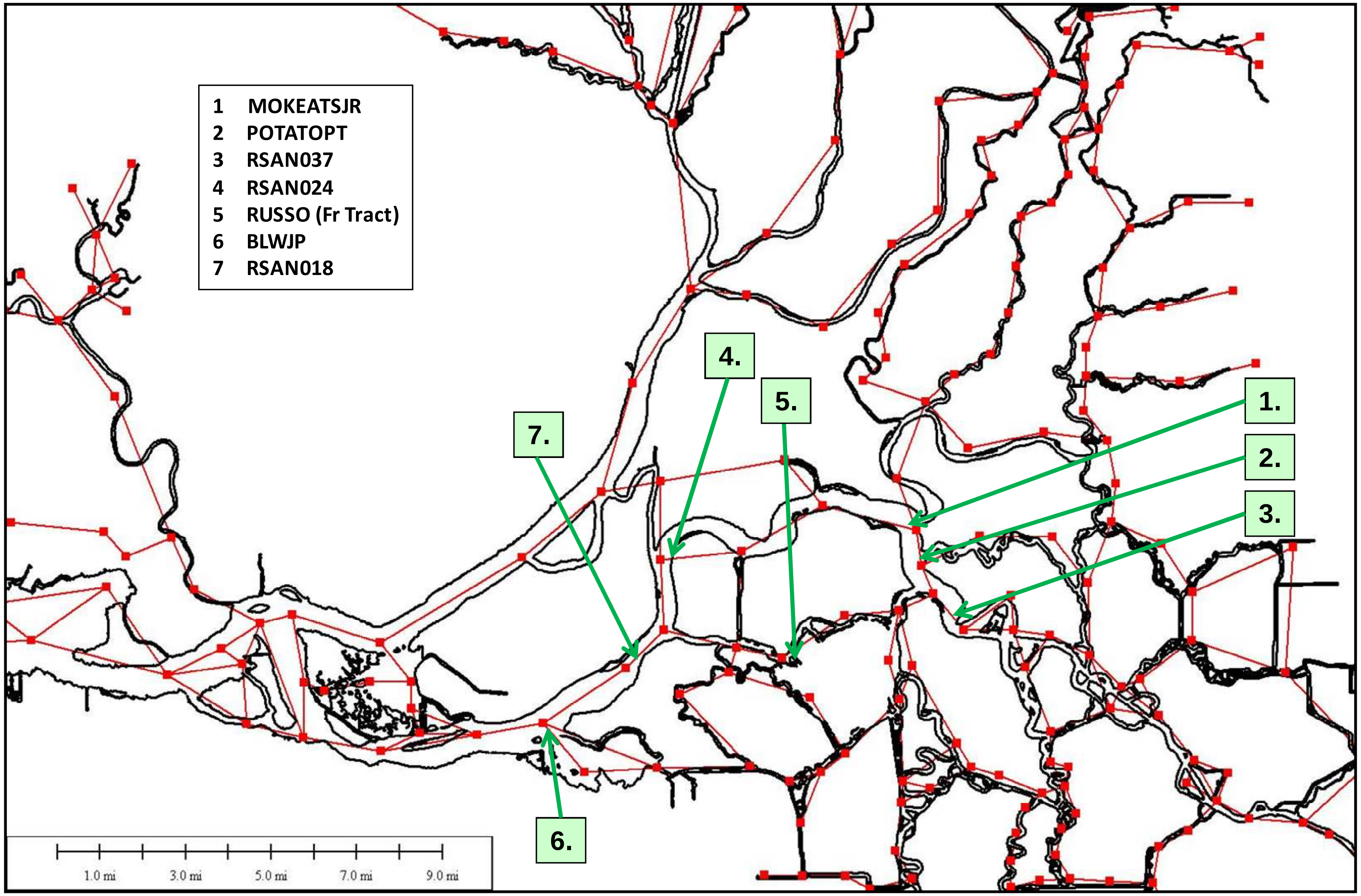


Figure 12-4 Model output locations on the lower San Joaquin River for the scenarios.

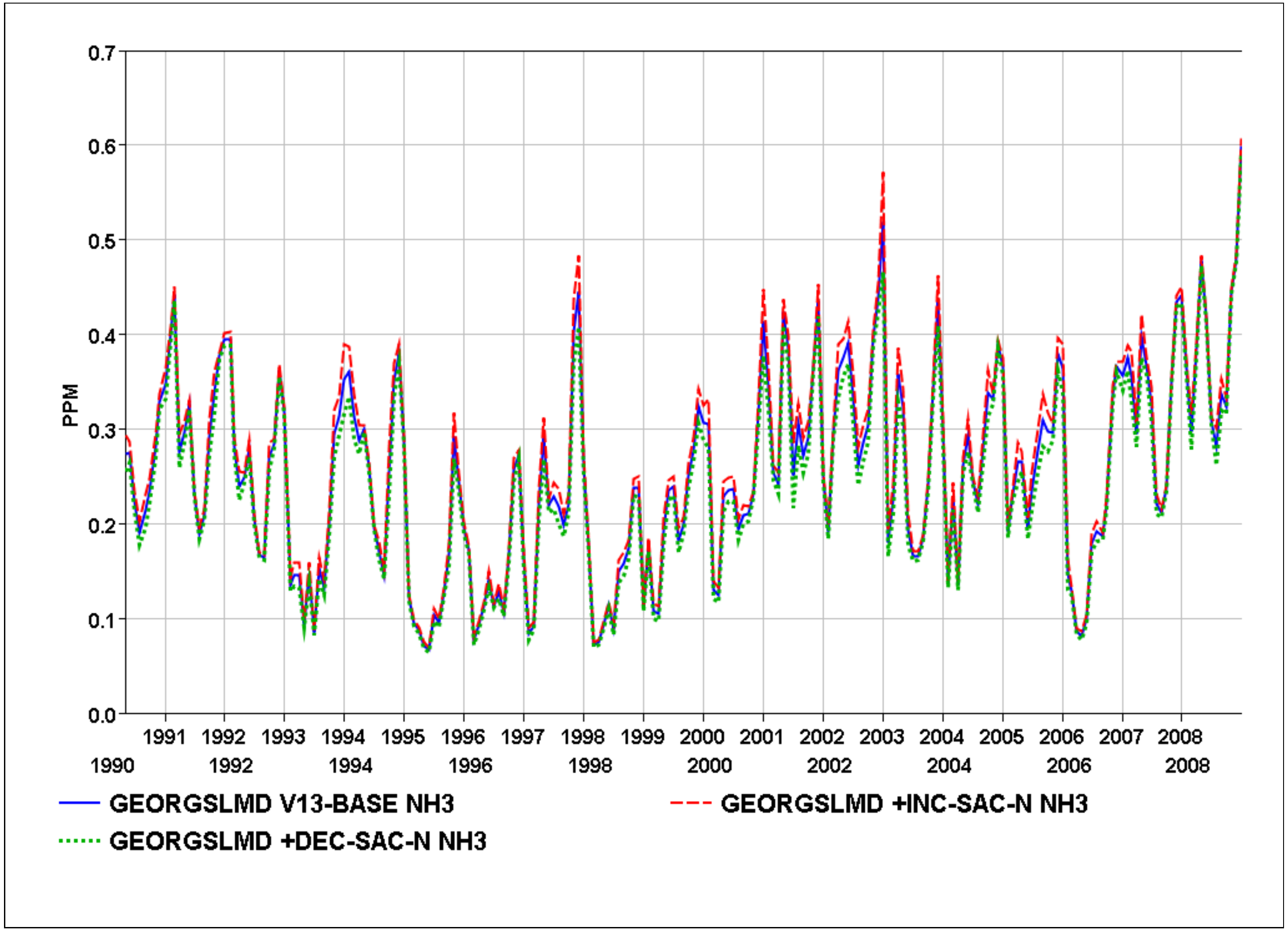


Figure 12-5 Changes in ammonia in Georgianna Slough for the scenarios changing Sacramento R. N-constituents.

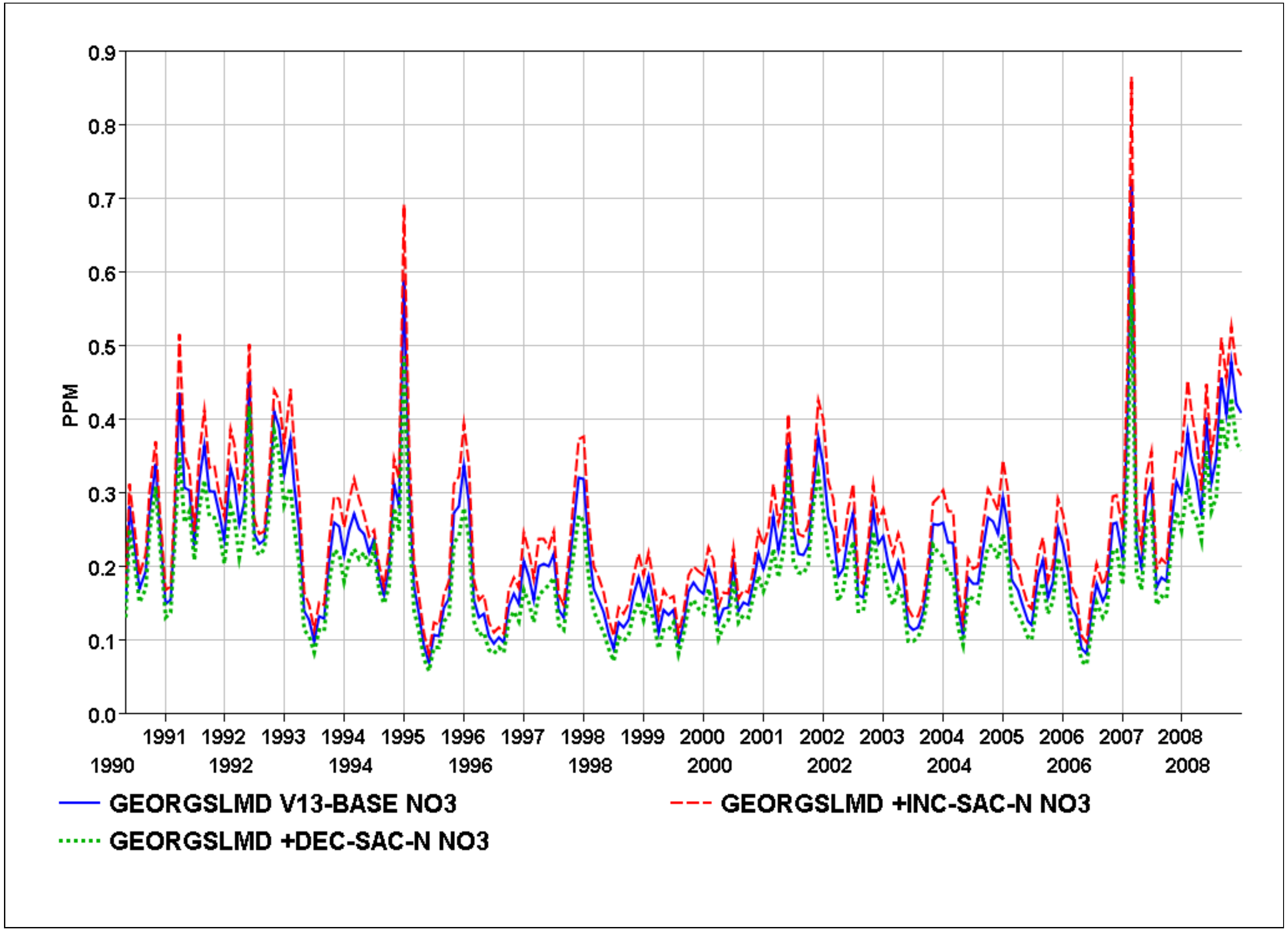


Figure 12-6 Changes in nitrate in Georgianna Slough for the scenarios changing Sacramento R. N-constituents.

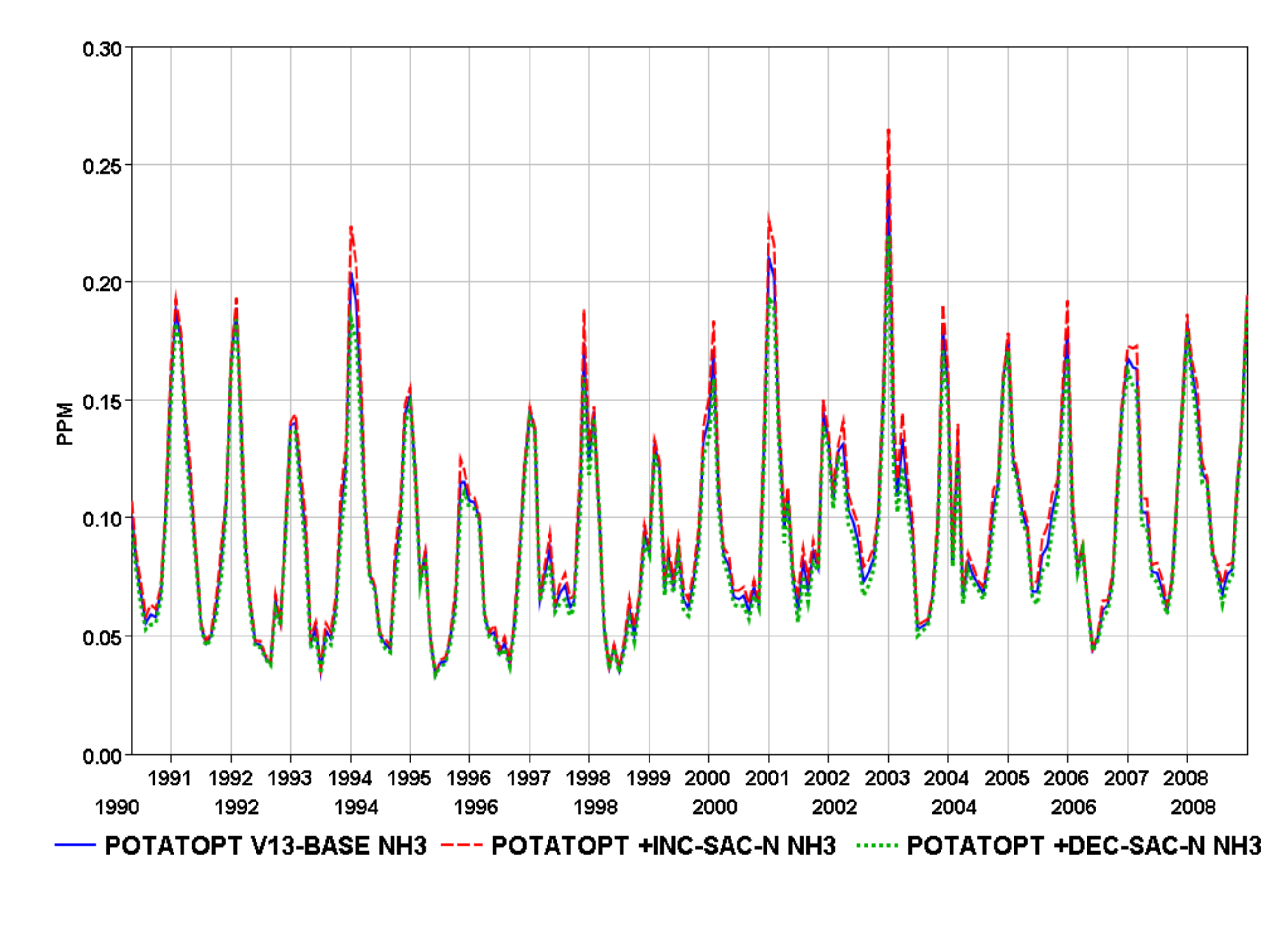


Figure 12-7 Changes in ammonia concentration at Potato Point for the scenarios changing Sacramento R. N-constituents.

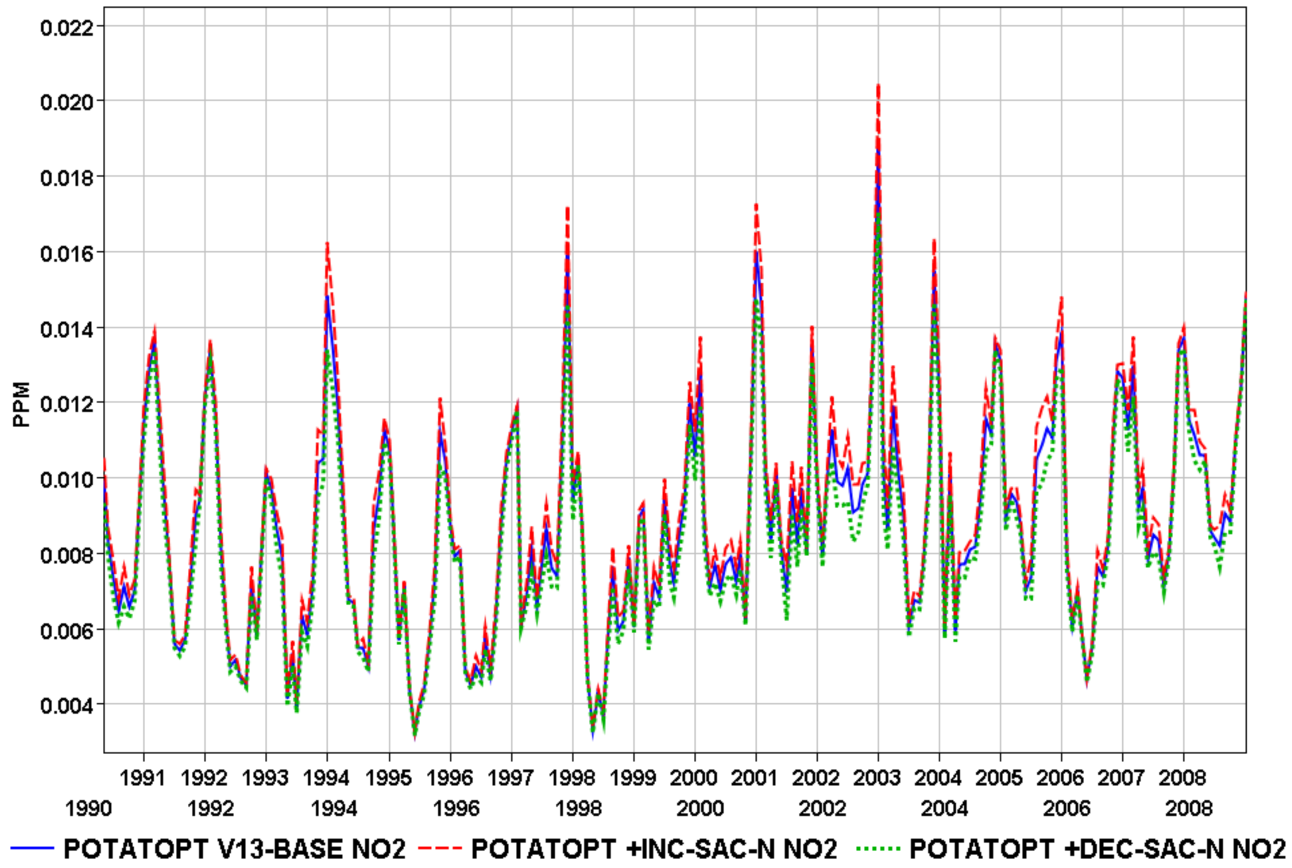


Figure 12-8 Changes in nitrite concentration at Potato Point for the scenarios changing Sacramento R. N-constituents.

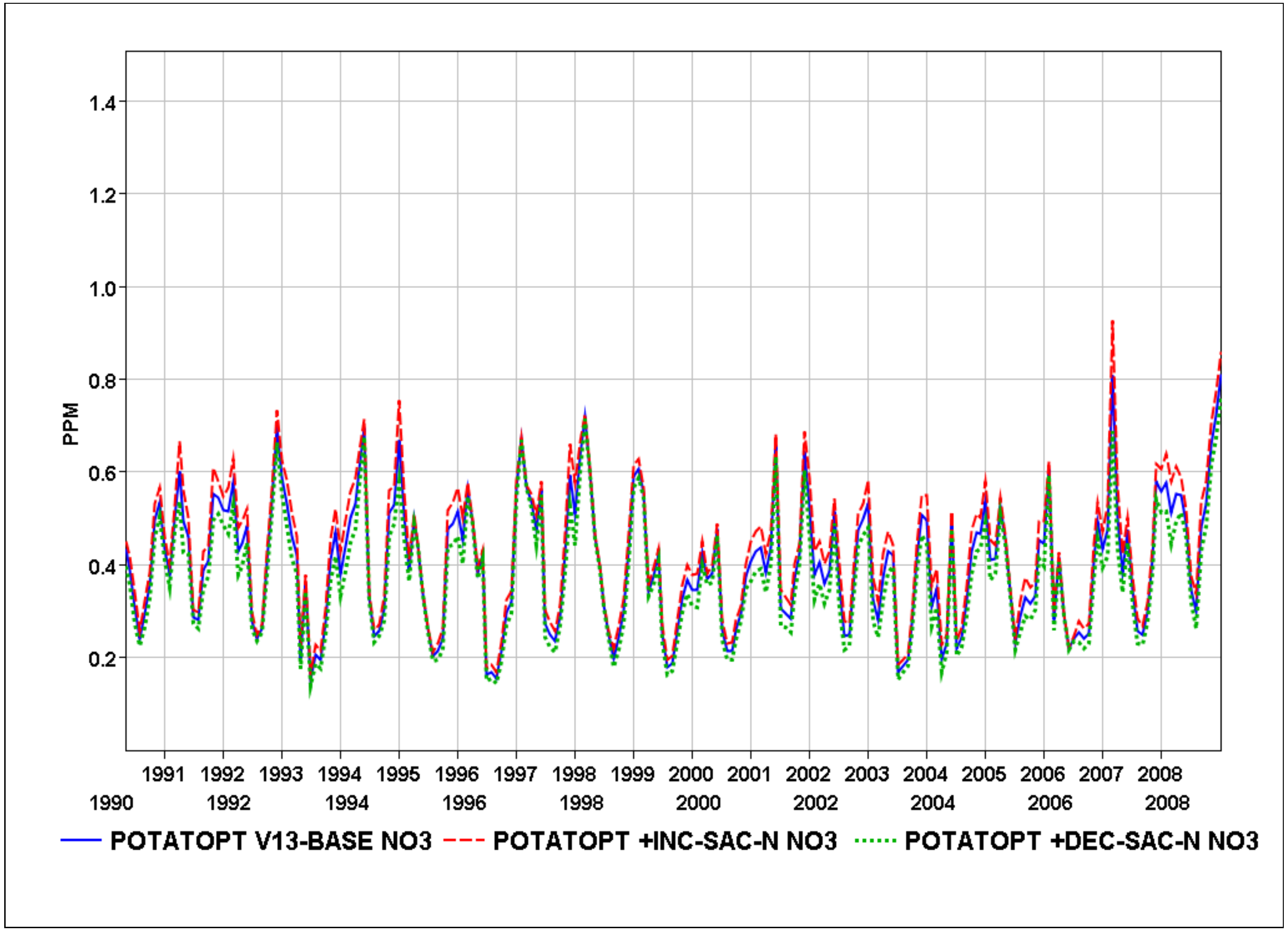


Figure 12-9 Changes in nitrate concentration at Potato Point for the scenarios changing Sacramento R. N-constituents.

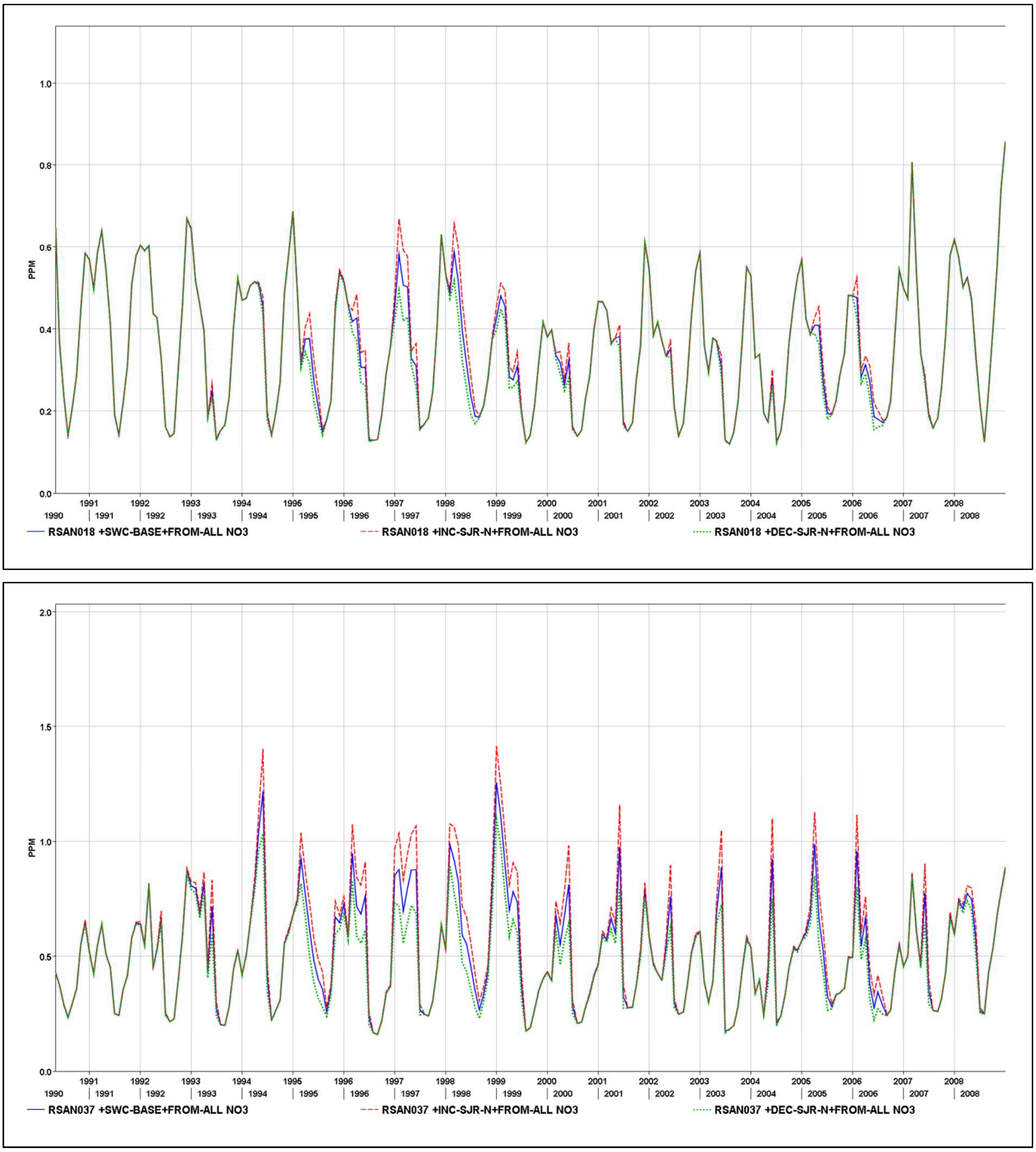


Figure 12-10 Nitrate concentration at downstream locations from the San Joaquin boundary after changing N-concentrations – RSAN018 and RSAN037.

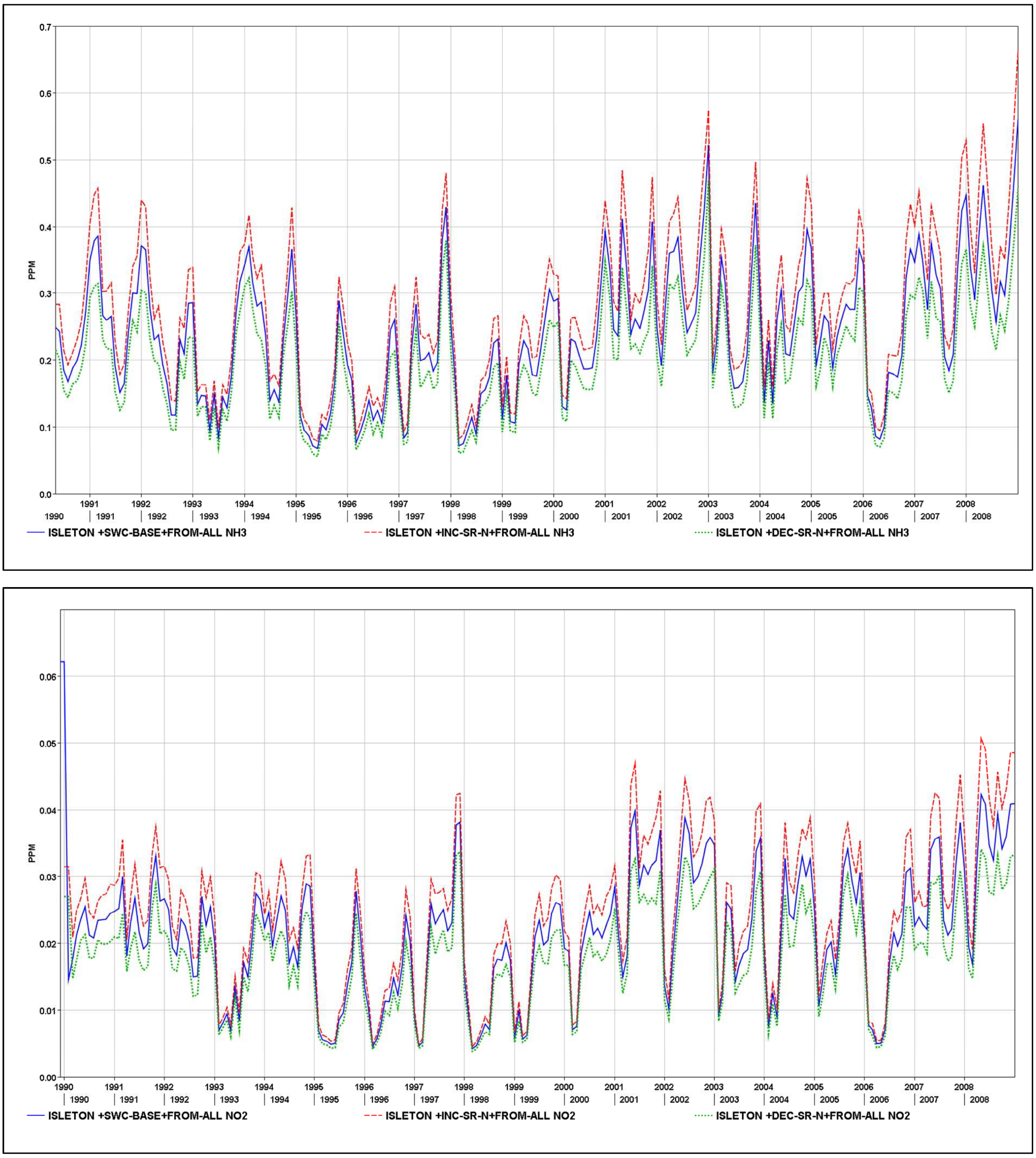
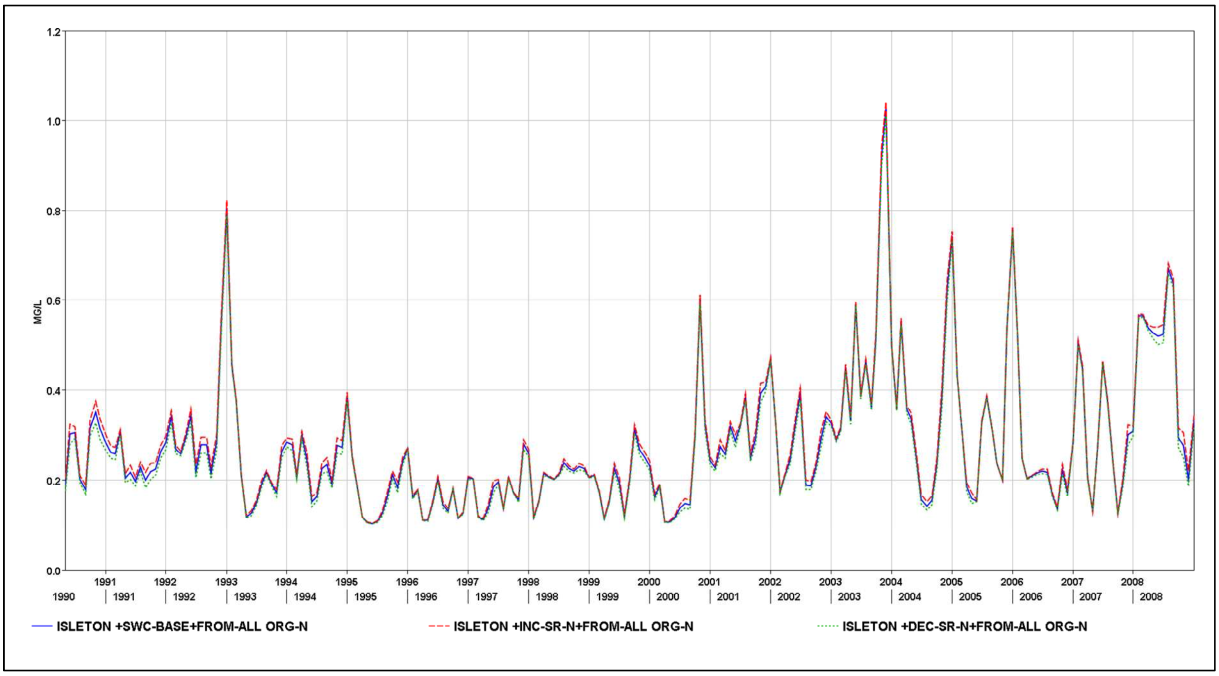


Figure 12-11 Changes in ammonia and nitrite at Isleton in the scenario changing Sac Regional N-constituents.



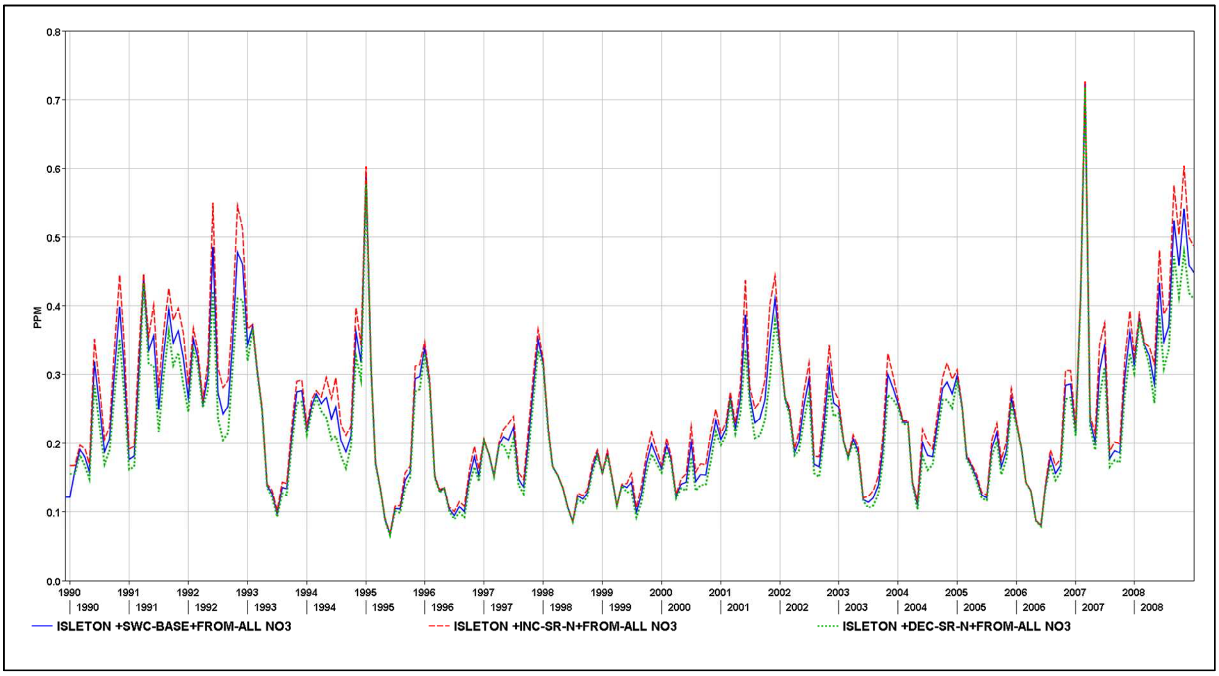
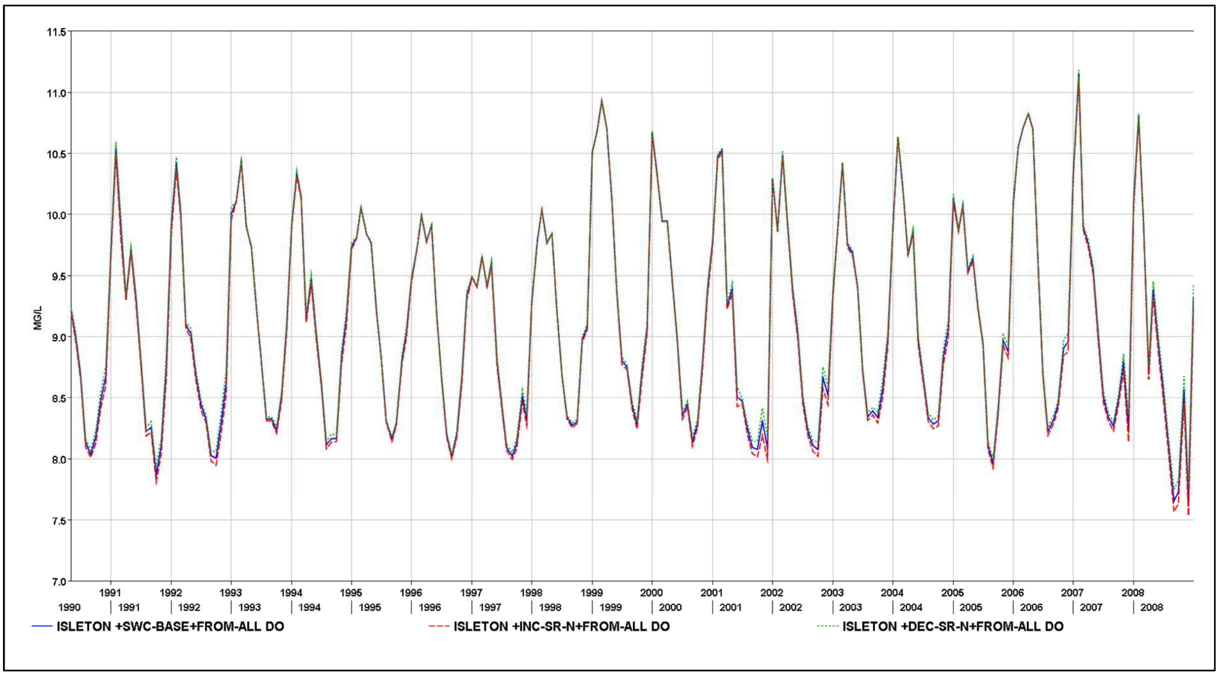


Figure 12-12 Changes in organic-N and nitrate at Isleton in the scenario changing Sac Regional N-constituents.



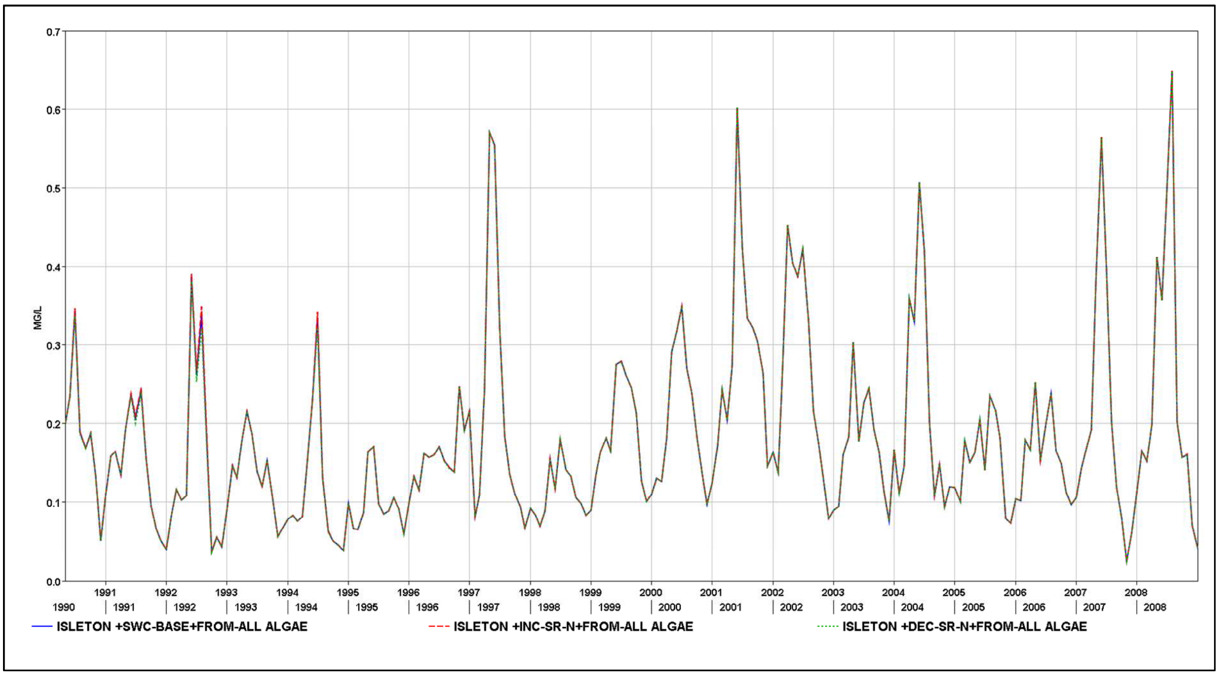


Figure 12-13 Changes in DO and chl-a/algae at Isleton in the scenario changing Sac Regional N-constituents.

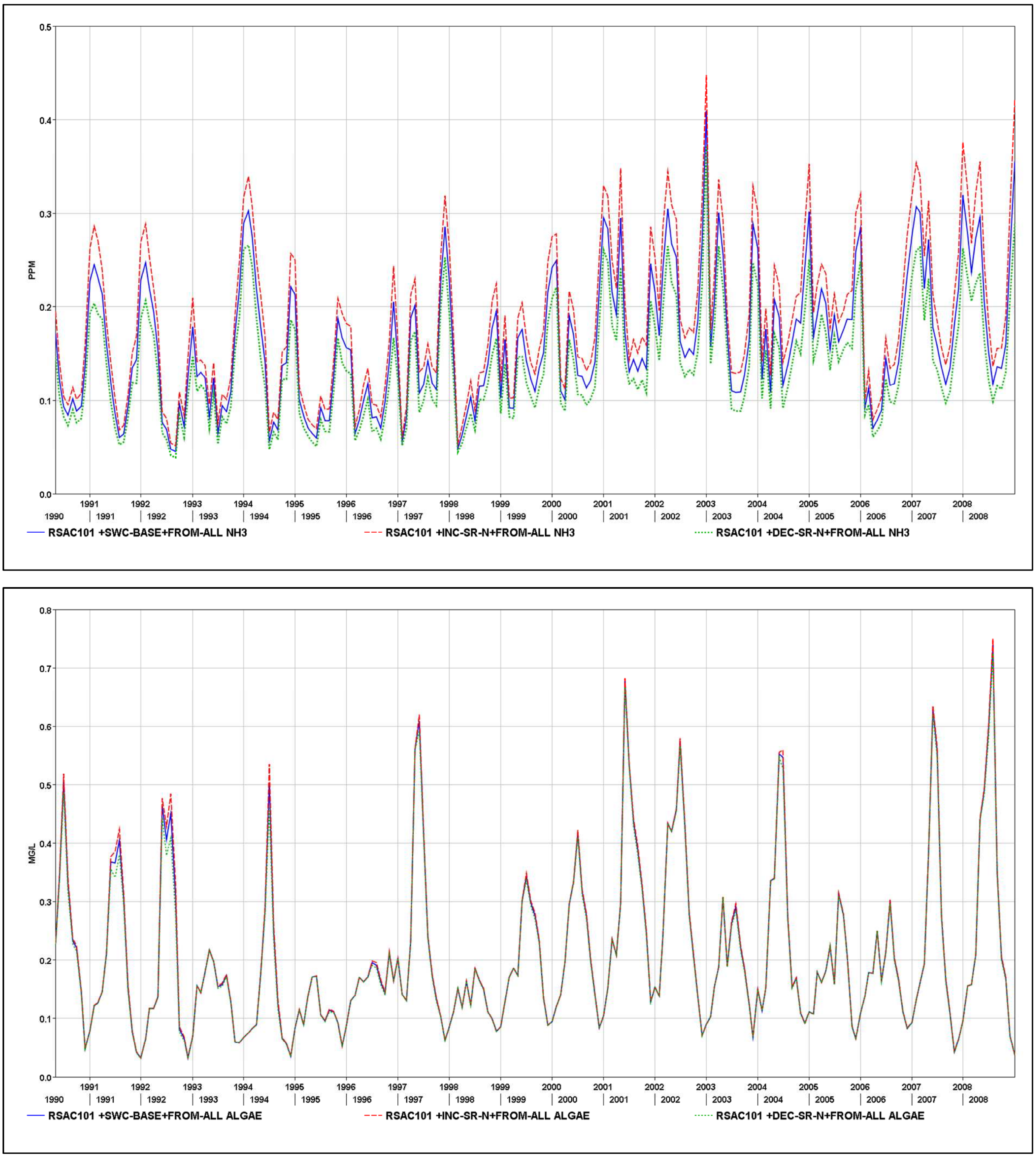
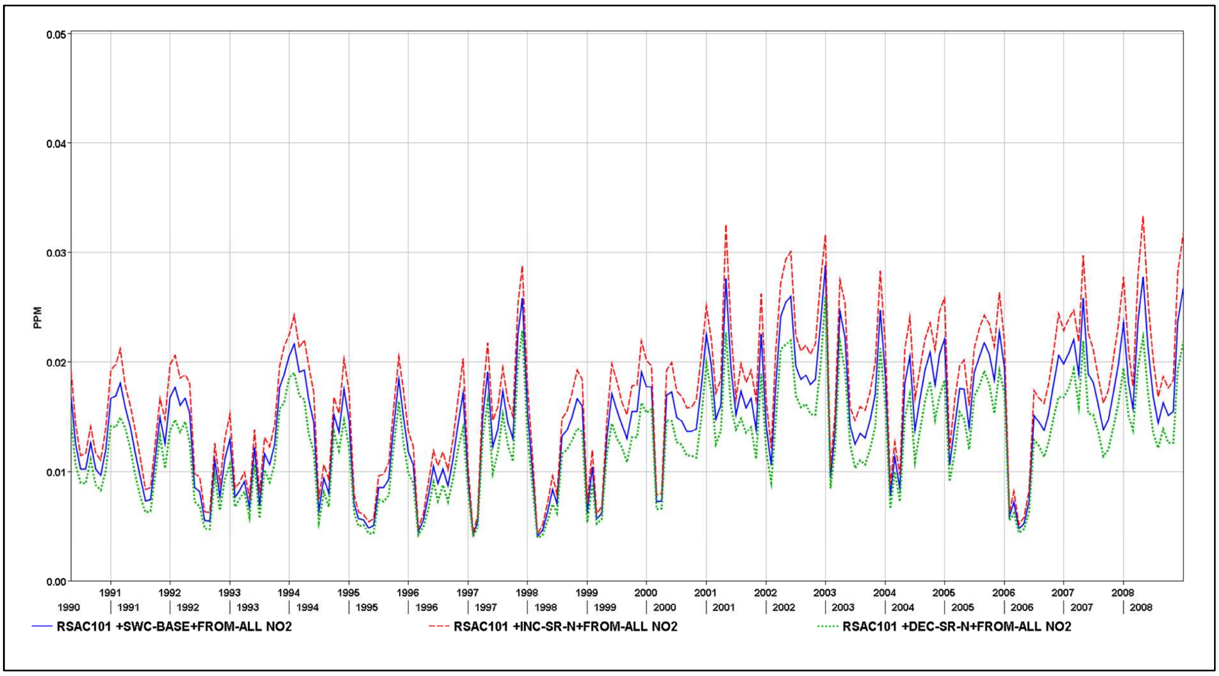


Figure 12-14 Changes in ammonia and chl-a/algae at Rio Vista in the scenario changing Sac Regional N-constituents.



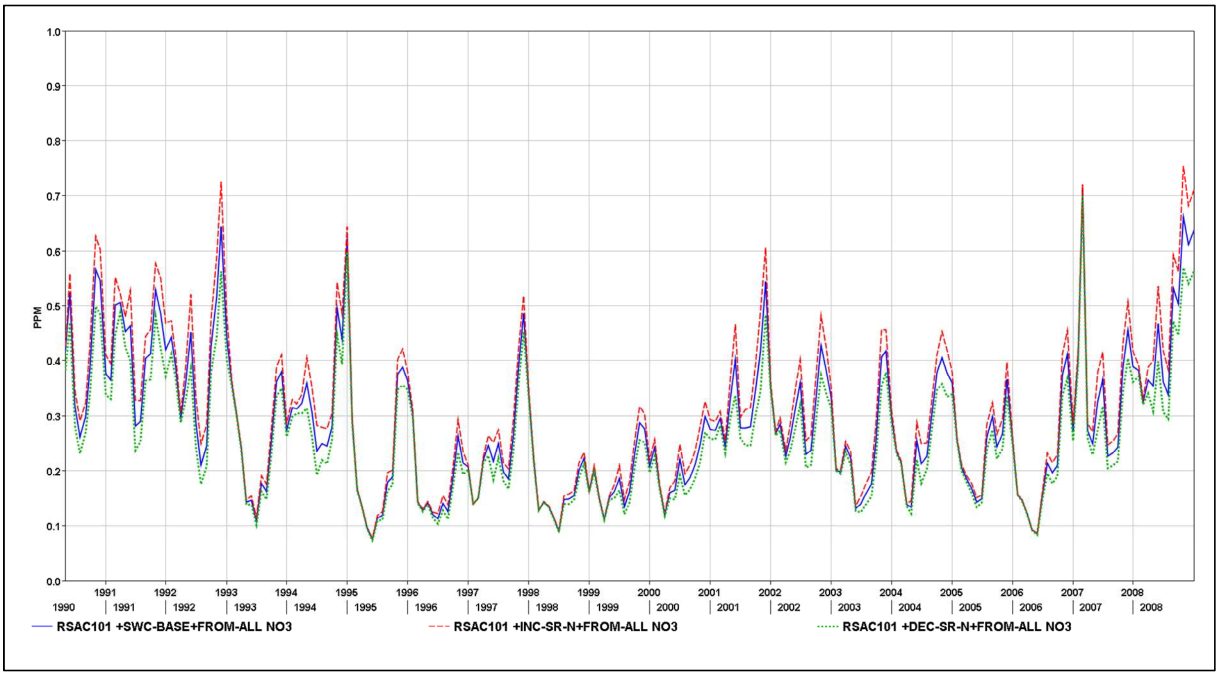


Figure 12-15 Changes in nitrite and nitrate at Rio Vista in the scenario changing Sac Regional N-constituents.

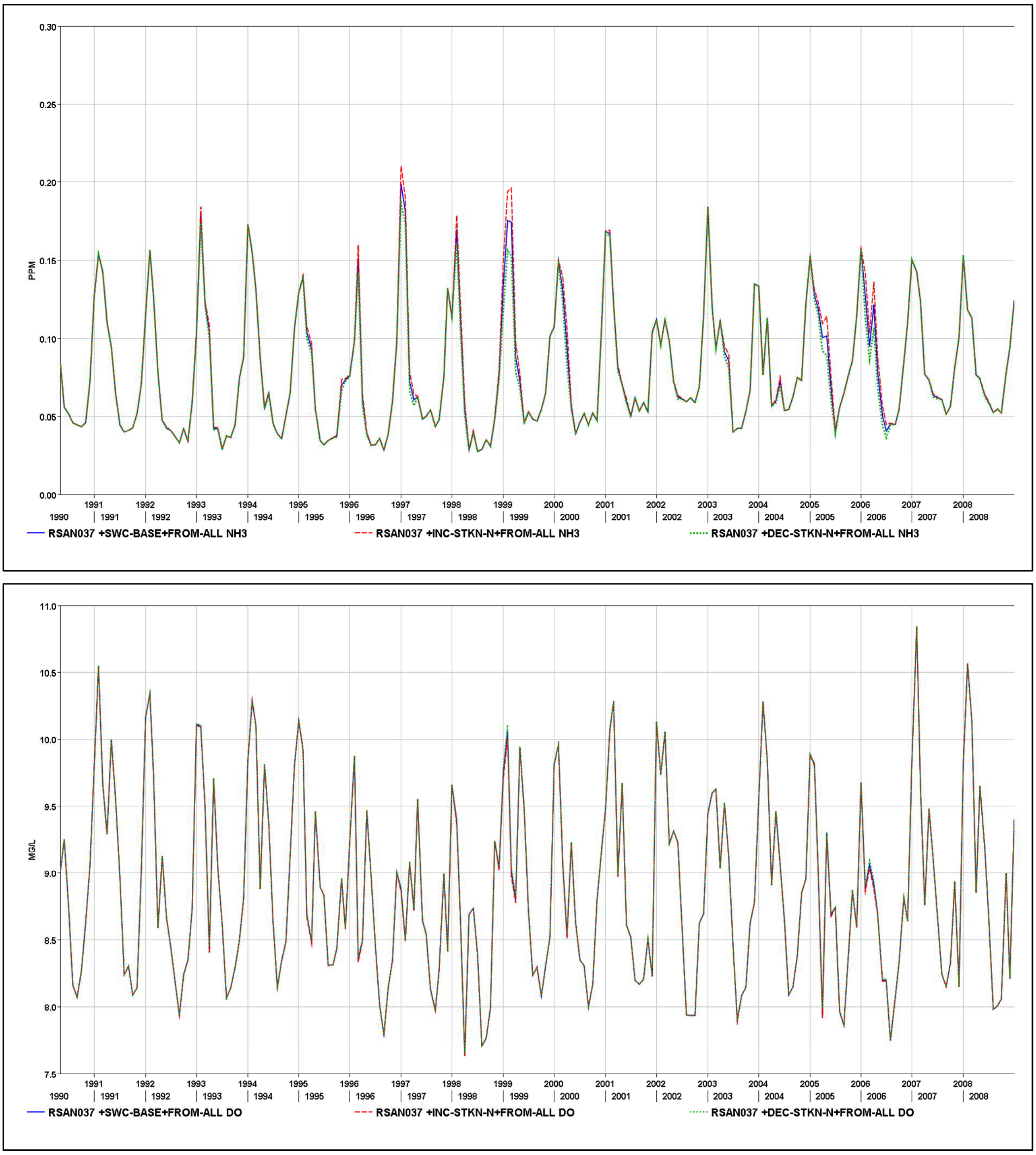


Figure 12-16 Ammonia and DO concentrations at RSAN037 downstream of the Stockton WWTP after changing wastewater concentrations.

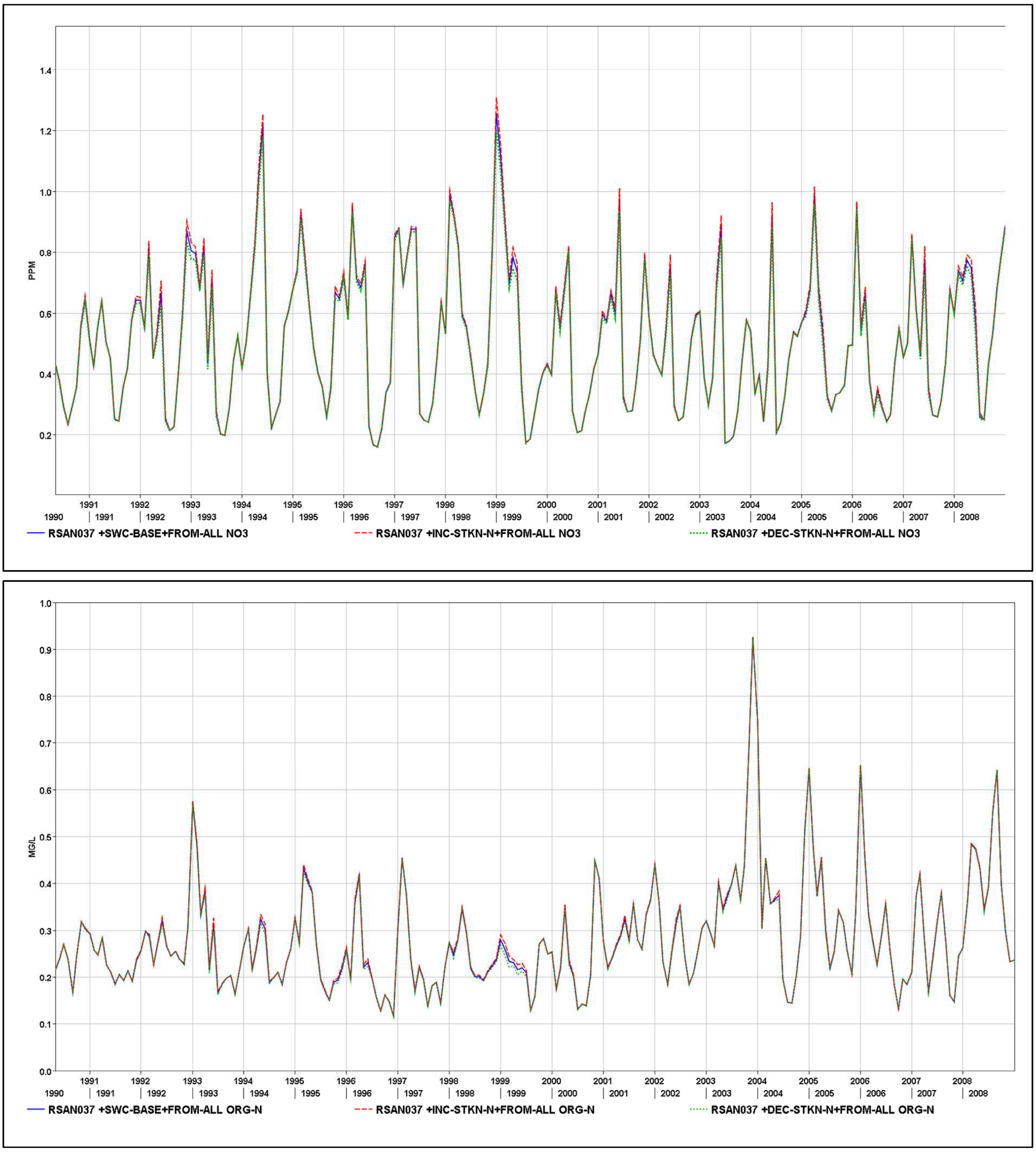


Figure 12-17 Nitrate and organic-N concentrations at RSAN037 downstream of the Stockton WWTP after changing wastewater concentrations.

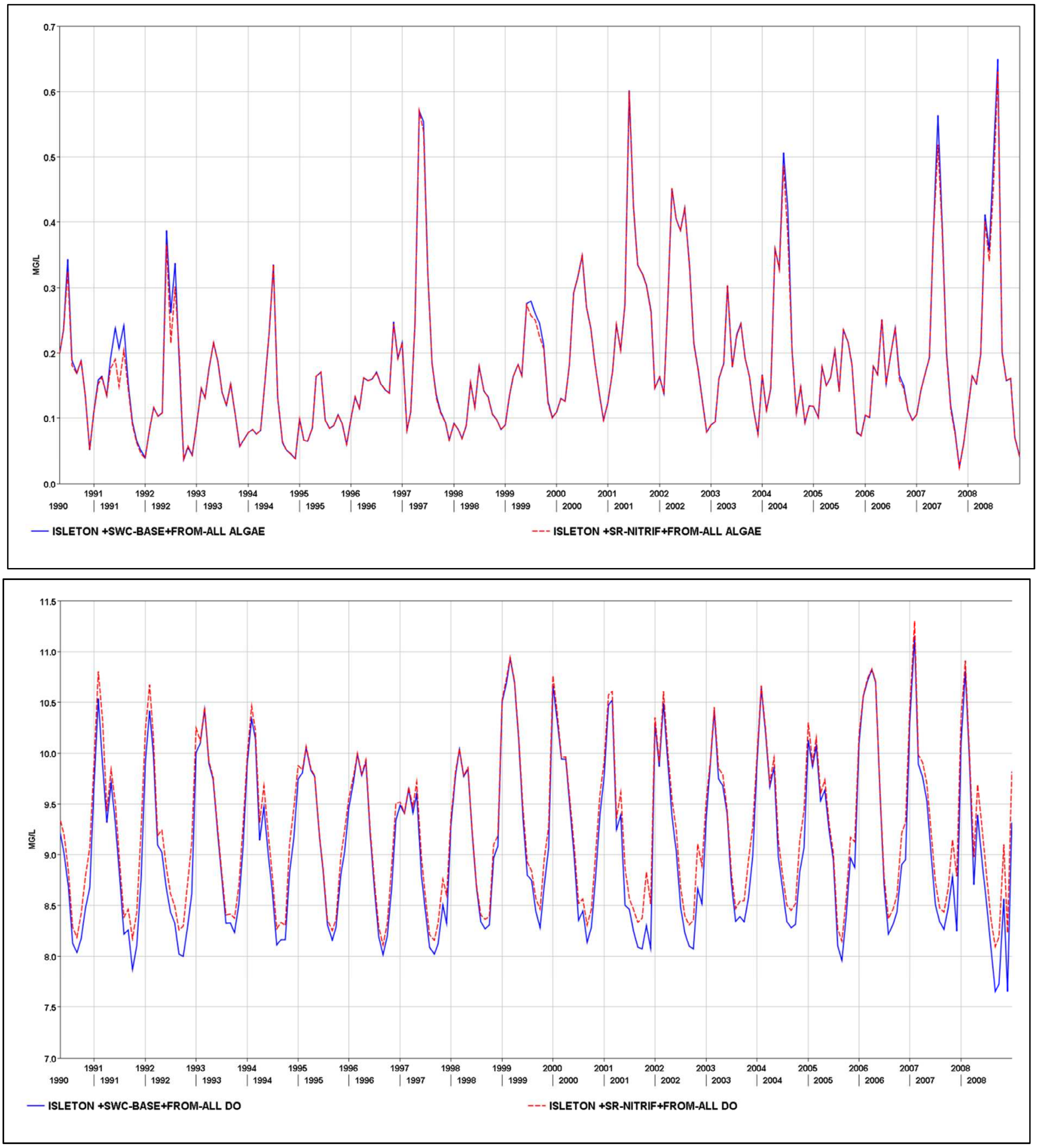
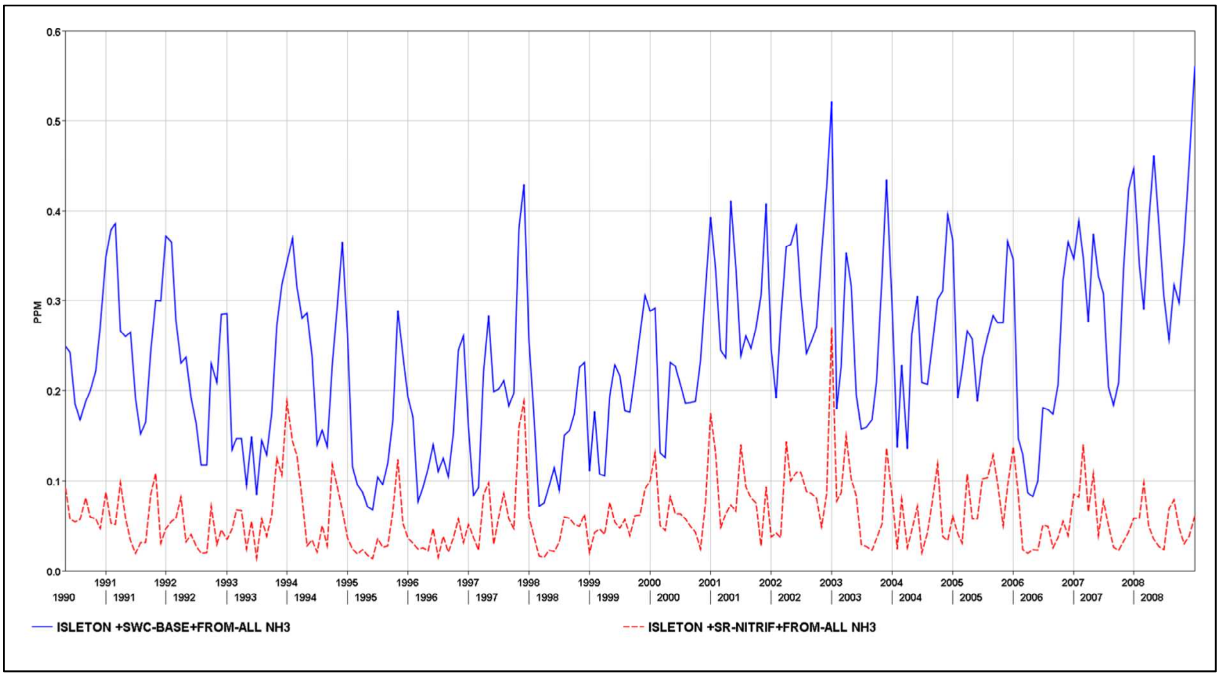


Figure 12-18 Chl-a/algae and DO concentrations at Isleton for the Sac Regional Nitrification scenario.



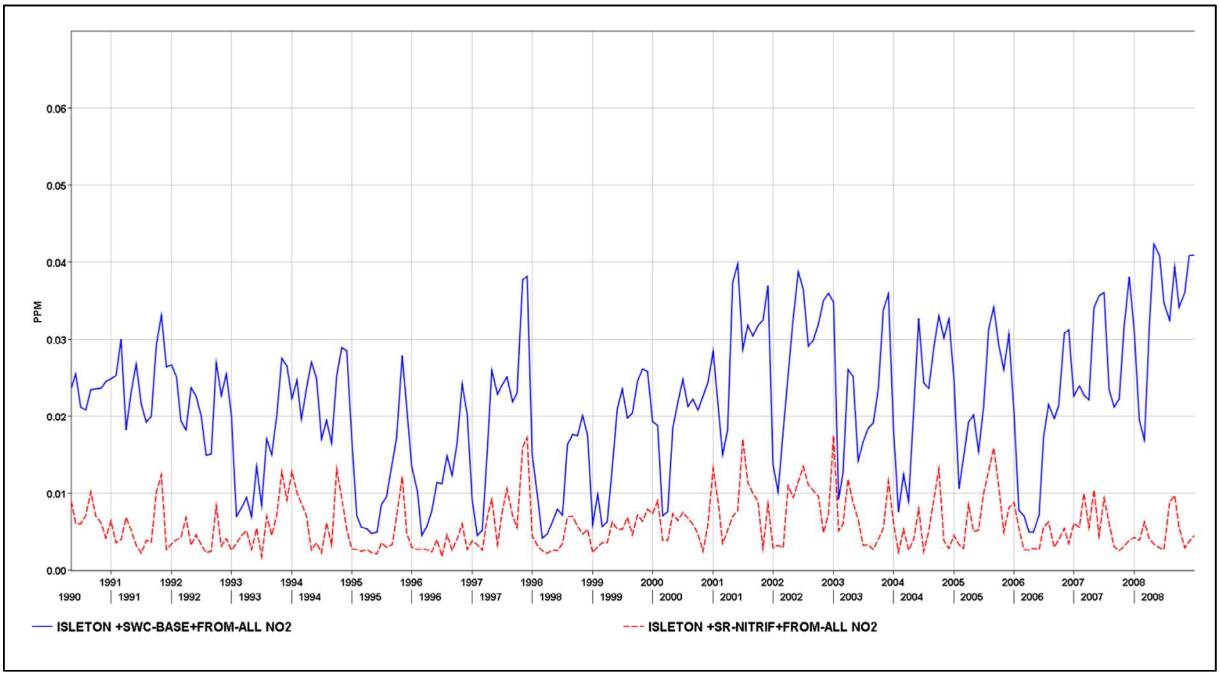


Figure 12-19 Nitrate and nitrate concentrations at Isleton for the Sac Regional Nitrification scenario.

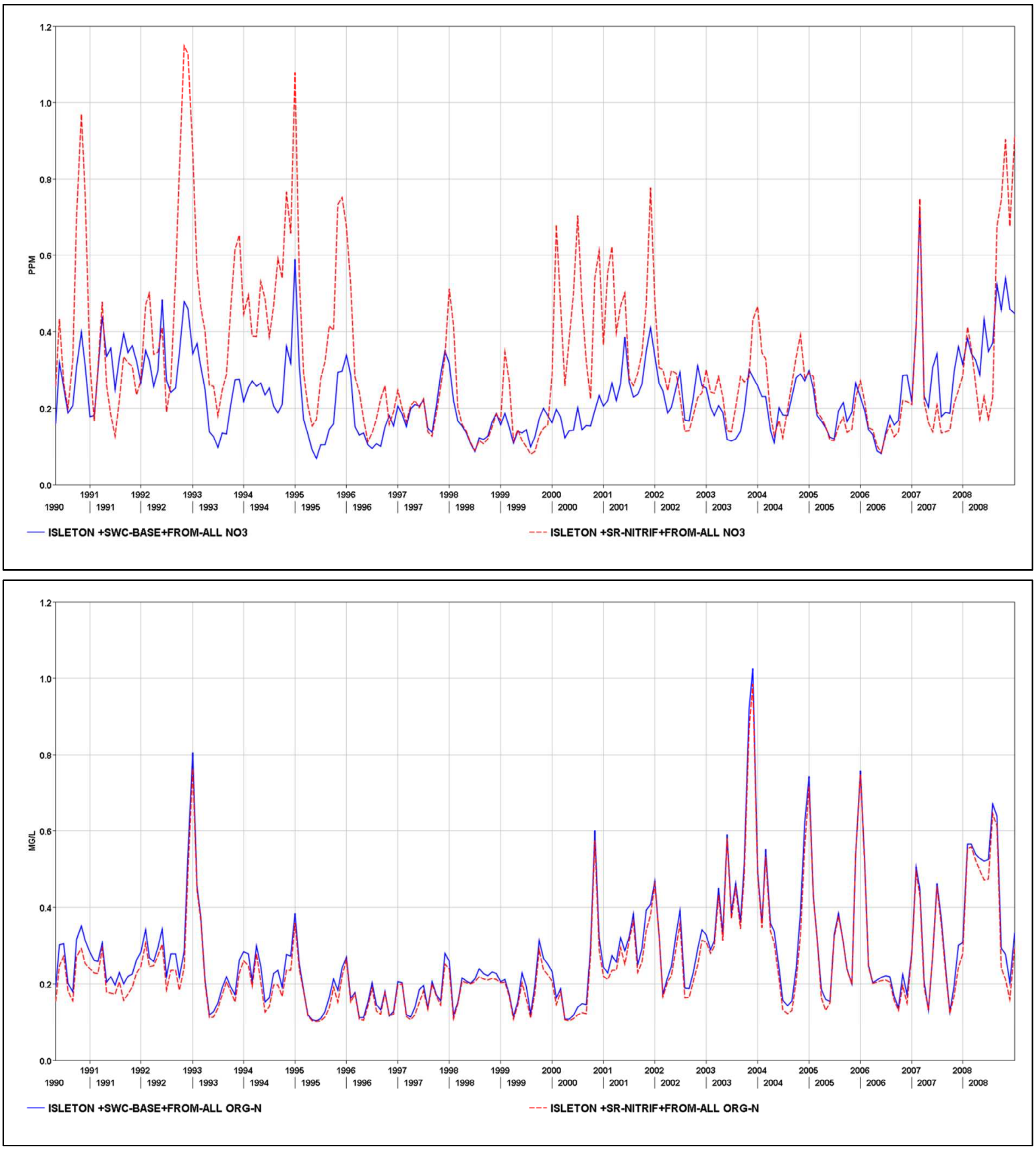
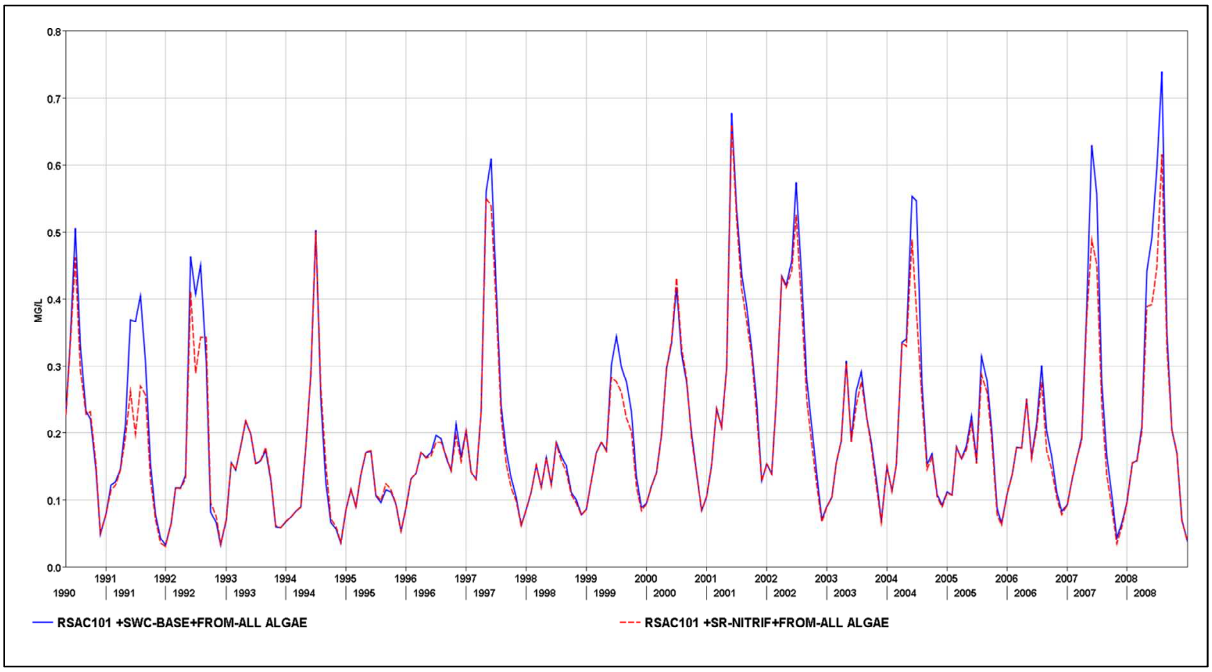


Figure 12-20 Nitrate and organic-N concentrations at Isleton for the Sac Regional Nitrification scenario



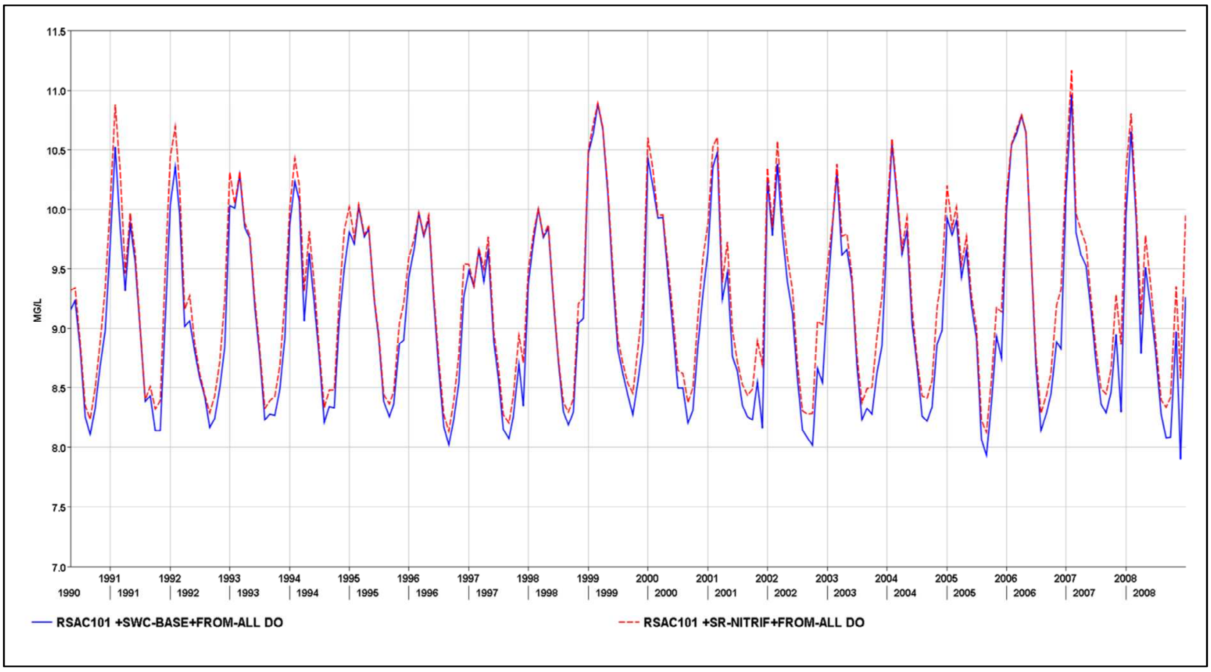


Figure 12-21 Chl-a/algae and DO concentrations at Rio Vista for the Sac Regional Nitrification scenario.

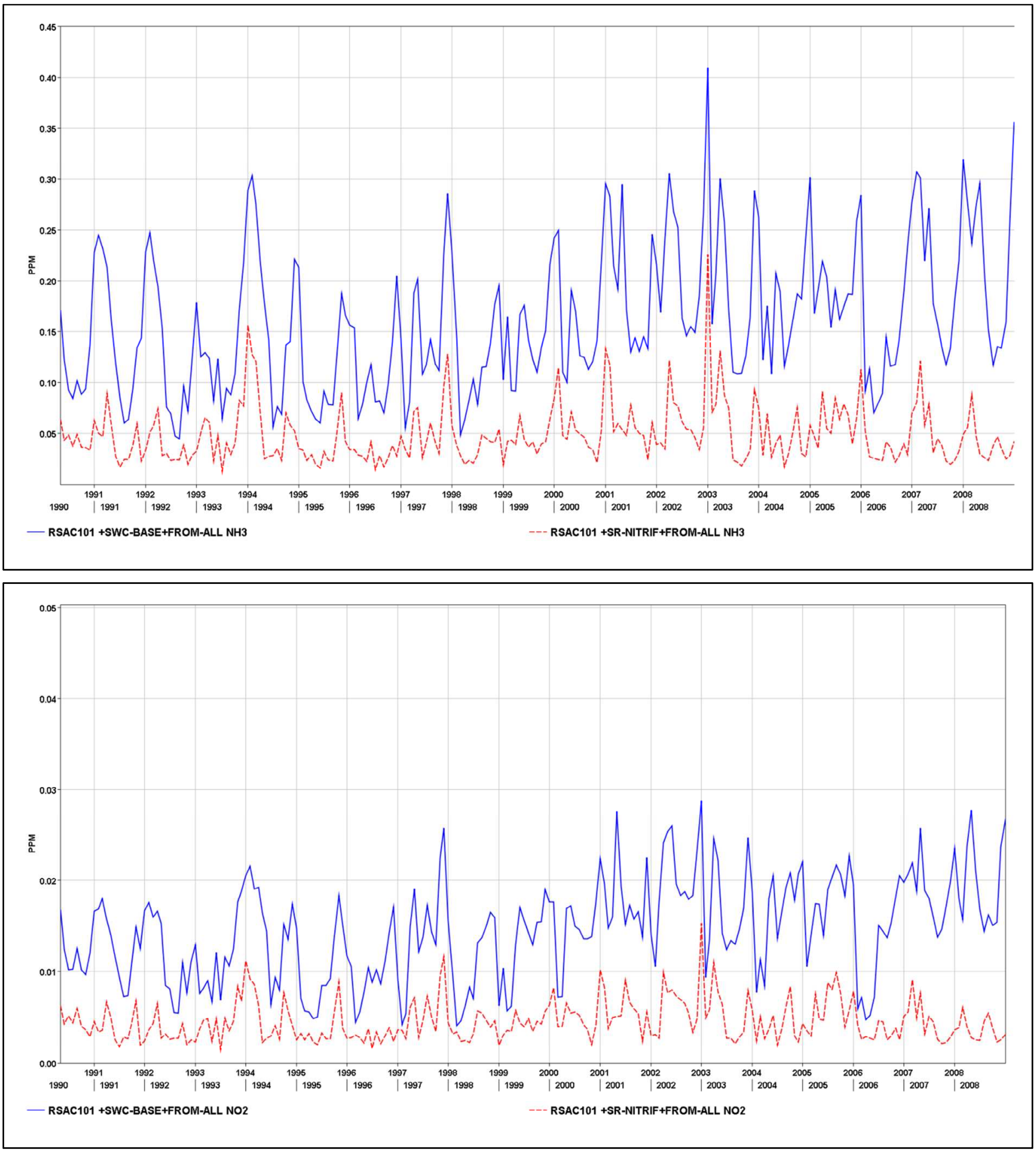


Figure 12-22 Ammonia and nitrite concentrations at Rio Vista for the Sac Regional Nitrification scenario.

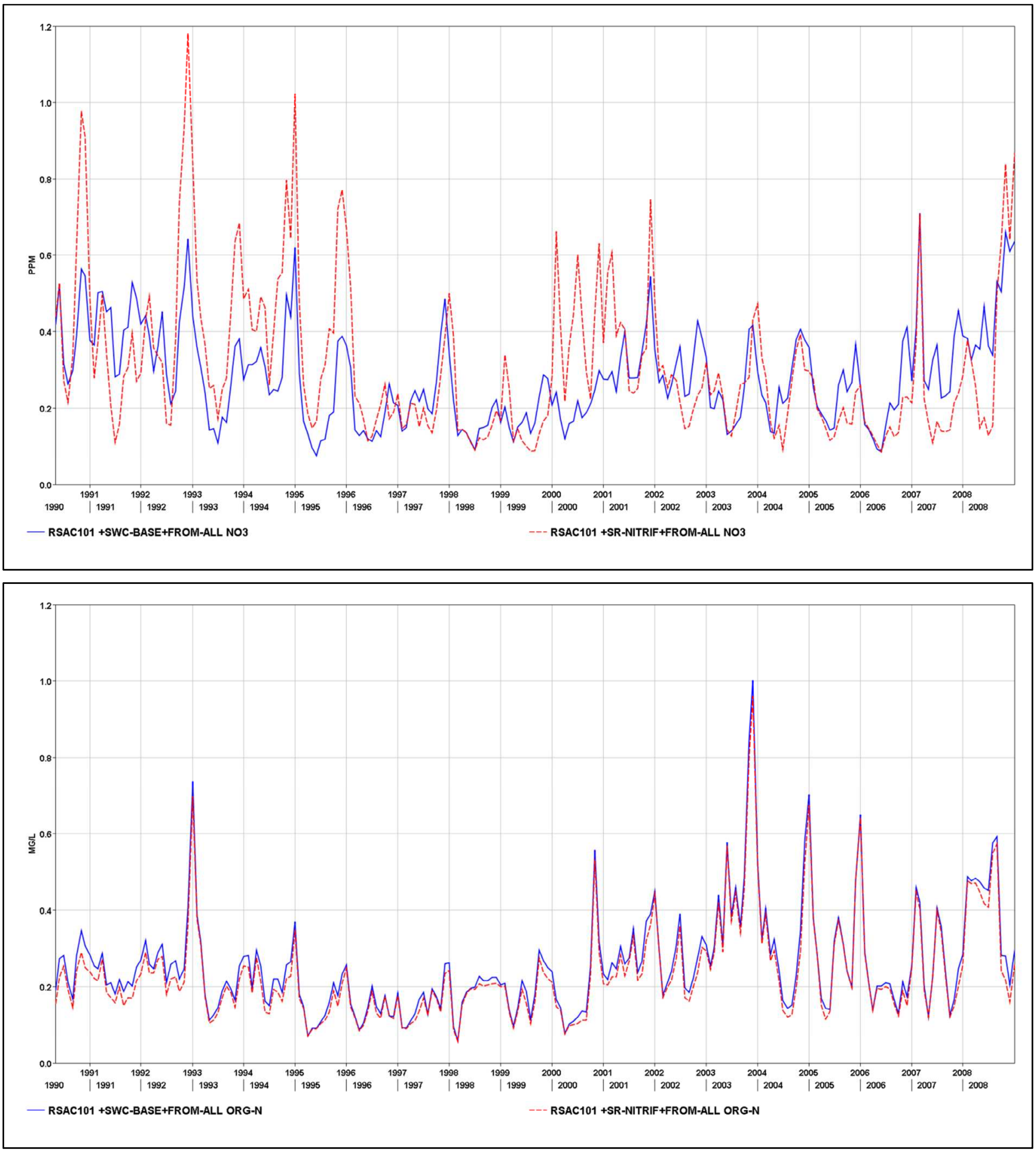


Figure 12-23 Nitrate and organic-N concentrations at Rio Vista for the Sac Regional Nitrification scenario.

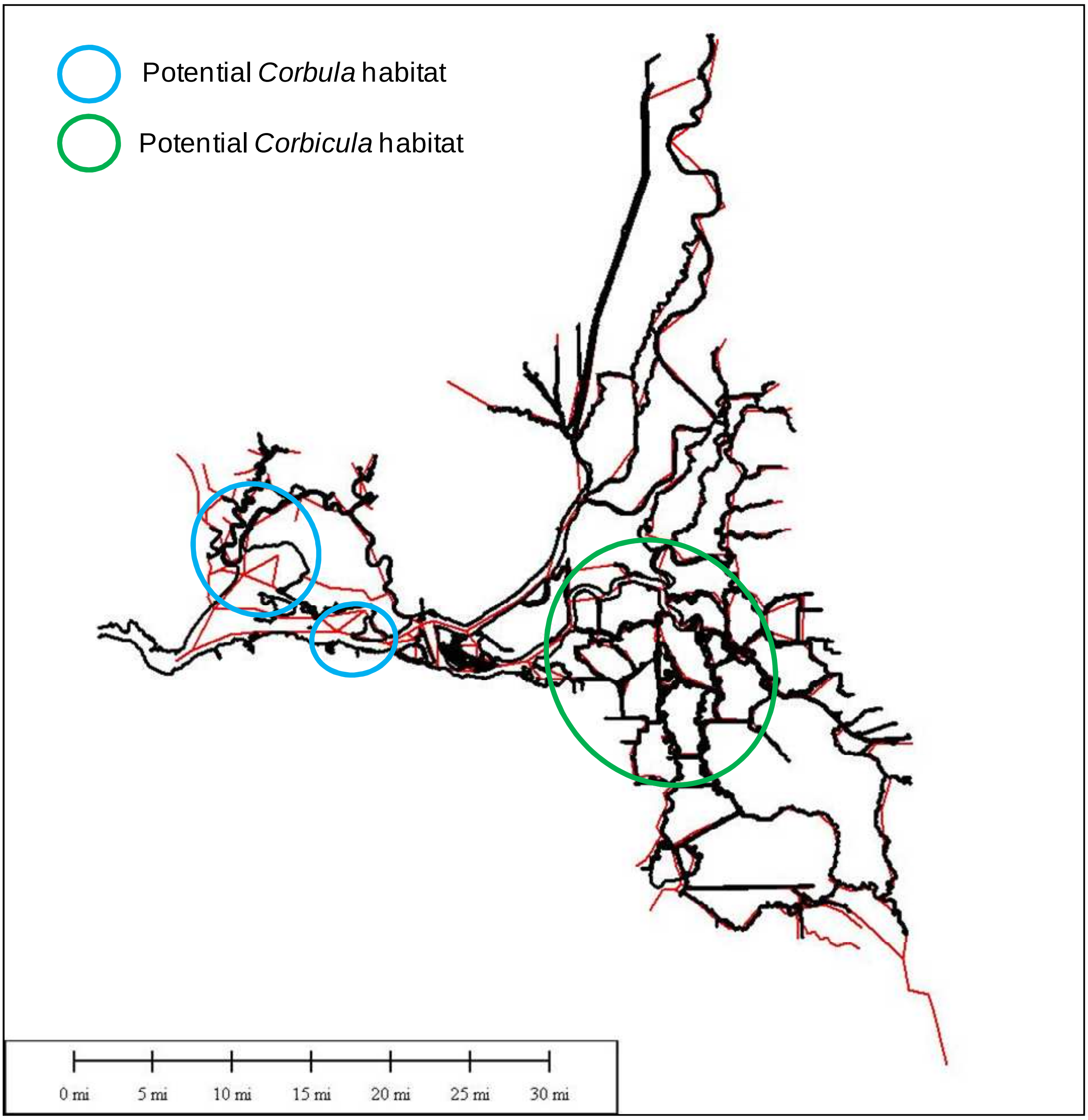


Figure 12-24 Suitable habitat areas for *Corbula* and *Corbicula* do not tend to overlap.

Table 12-1 Results from nitrification scenarios at RSAC101 (algae and ammonia).

Percent Change from Base due to Sac Regional switch to nitrification.

RSAC101 Algae	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
Average	-0.75	-0.45	-0.33	-0.57	-2.25	-6.85	-11.08	-8.29	-3.84	-3.61	-4.14	-2.61
Average Dry+Critical	-1.22	-1.11	-0.74	-1.13	-4.05	**-11.23**	**-17.42**	**-13.22**	-3.04	-7.08	-6.12	-3.95
Average Wet+AbvNormal	-0.32	-0.03	-0.08	-0.18	-0.72	-2.87	-4.13	-4.24	-4.38	-2.14	-3.38	-1.92

RSAC101 NH_3	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
Average	-72.47	-66.55	-64.98	-63.57	-72.16	-71.78	-67.50	-63.37	-66.71	-67.70	-72.20	-76.81
Average Dry+Critical	-77.85	-72.12	-70.50	-67.51	-75.80	-74.25	**-62.82**	**-60.08**	**-62.51**	-69.27	-72.93	-78.38
Average Wet+AbvNormal	-67.33	-61.63	-61.54	-59.63	-68.39	-69.56	**-69.48**	**-64.57**	**-69.93**	-64.76	-70.60	-75.47

Table 12-2 Results from nitrification scenarios at RSAC101 (nitrate and nitrite).

Percent Change from Base due to Sac Regional switch to nitrification.

RSAC101 NO_2	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
Average	-71.00	-60.87	-56.82	-57.20	-68.75	-70.68	-67.49	-64.08	-67.59	-68.21	-72.50	-76.98
Average Dry+Critical	-77.81	-71.04	-69.62	-67.39	-75.98	-75.31	**-64.30**	**-61.55**	**-64.02**	-70.05	-73.33	-78.73
Average Wet+AbvNormal	-64.61	-52.92	-48.04	-48.91	-61.86	-66.58	**-68.18**	**-64.71**	**-70.39**	-64.95	-70.75	-75.48

RSAC101 NO_3	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
Average	26.98	39.81	32.79	19.27	11.28	3.84	-3.16	3.30	13.99	11.47	6.35	11.98
Average Dry+Critical	24.16	20.12	20.88	9.64	-5.54	**-22.04**	**-35.02**	**-21.55**	8.42	-0.68	7.59	15.71
Average Wet+AbvNormal	33.70	53.35	41.21	26.17	26.74	28.82	27.74	25.32	20.84	15.18	1.88	5.98

Table 12-3 Results from nitrification scenarios at Pt. Sacramento (algae and ammonia).

Percent Change from Base due to Sac Regional switch to nitrification.

PO649 Algae	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
Average	-1.97	-0.70	-0.71	-0.97	-6.08	-13.46	-20.29	-20.31	-13.15	-10.30	-11.33	-7.80
Average Dry+Critical	-3.54	-1.71	-1.60	-1.83	-11.41	**-24.09**	**-33.28**	**-29.68**	-16.69	-16.24	-13.96	-8.14
Average Wet+AbvNormal	-1.13	-0.07	-0.18	-0.31	-1.88	-6.05	**-10.45**	**-13.85**	**-11.61**	-7.03	-9.80	-7.25

PO649 NH_3	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
Average	-62.15	-57.92	-57.49	-55.88	-58.93	-48.56	-40.37	-34.78	-33.27	-37.12	-37.37	-54.36
Average Dry+Critical	-62.67	-59.89	-58.98	-56.54	-55.22	-38.04	**-28.25**	**-25.36**	**-23.42**	-35.85	-36.77	-53.09
Average Wet+AbvNormal	-60.97	-55.21	-56.50	-54.21	-60.49	-56.49	-50.33	-40.64	-39.79	-39.27	-39.54	-55.86

Table 12-4 Results from nitrification scenarios at Pt. Sacramento (nitrate and nitrite).

Percent Change from Base due to Sac Regional switch to nitrification.

PO649 NO_2	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
Average	-62.46	-56.36	-54.73	-54.18	-58.96	-49.41	-41.57	**-36.52**	**-35.10**	-38.75	-38.49	-55.41
Average Dry+Critical	-63.50	-60.42	-59.54	-57.44	-56.61	-39.44	-29.09	-26.31	-24.53	-37.39	-37.86	-54.20
Average Wet+AbvNormal	-60.84	-52.12	-51.27	-50.61	-59.36	-56.77	-51.73	-42.94	-42.20	-40.87	-40.65	-56.84

PO649 NO_3	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
Average	-0.37	14.88	17.28	4.39	-9.26	**-13.89**	**-13.66**	-10.54	-8.98	-8.32	-11.68	-10.73
Average Dry+Critical	0.84	-4.21	-0.13	-8.10	**-26.08**	**-29.85**	**-31.87**	**-19.36**	-12.01	-17.08	-14.83	-7.27
Average Wet+AbvNormal	2.11	26.84	29.24	13.12	6.84	2.08	3.76	-1.00	-4.82	-5.52	-12.23	-15.10

Table 12-5 12-6 Results from nitrification scenarios at Jersey Point (algae and ammonia).

Percent Change from Base due to Sac Regional switch to nitrification.

RSAN018 Algae	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
Average	-2.38	-0.68	-0.62	-1.26	-7.93	-12.22	-20.34	-21.00	-13.96	-11.09	-12.54	-9.13
Average Dry+Critical	-3.52	-1.65	-1.51	-2.30	**-14.63**	**-23.89**	**-34.49**	**-31.29**	**-16.82**	-6.84	-8.96	-8.00
Average Wet+AbvNormal	-1.83	-0.08	-0.07	-0.41	-2.16	-4.04	-9.55	**-13.16**	**-12.80**	**-18.19**	**-21.91**	**-14.81**

RSAN018 NH_3	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
Average	-62.46	-51.75	-47.55	-44.57	-49.60	-41.77	-35.53	-30.94	-32.47	-40.04	-46.64	-62.00
Average Dry+Critical	-67.77	-61.15	-59.90	-54.17	-55.50	-42.16	**-30.77**	**-26.42**	**-25.85**	**-39.74**	-46.23	-62.28
Average Wet+AbvNormal	-57.52	-44.10	-38.50	-37.32	-43.27	-40.87	**-38.96**	**-33.06**	**-36.62**	**-41.14**	-47.29	-62.12

Table 12-7 Results from nitrification scenarios at Jersey Point (nitrate and nitrite).

Percent Change from Base due to Sac Regional switch to nitrification.

RSAN018 NO_2	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Average	-63.16	-52.24	-47.87	-45.41	-50.82	-43.57	-37.50	-32.96	-34.48	-41.84	-47.86	-62.99
Average Dry+Critical	-68.66	-61.85	-60.60	-55.24	-57.06	-44.09	-32.18	-27.74	-27.36	-41.48	-47.44	-63.32
Average Wet+AbvNormal	-58.07	-44.41	-38.52	-37.86	-44.19	-42.47	-41.33	-35.60	-39.04	-42.86	-48.43	-63.03

RSAN018 NO_3	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Average	-4.49	6.25	4.18	-3.90	-13.07	-15.32	-16.95	-12.61	-8.20	-7.67	-11.08	-10.89
Average Dry+Critical	-1.26	-8.60	-6.27	-11.69	-26.04	-28.44	-33.24	-21.80	-10.07	-16.66	-14.21	-7.39
Average Wet+AbvNormal	-3.66	15.71	11.05	1.50	-0.28	-2.98	-1.08	-3.27	-5.06	-4.98	-11.81	-15.25

13 Adequacy of QUAL's Current Formulation and Potential Areas for Model Development

13.1 Current Formulation- Strengths and Weaknesses

One of the great strengths of the water temperature and nutrient formulations in QUAL is their simplicity. Because there are invariably constituent concentrations missing at boundaries and within the model domain in nutrient models, as was the case in the Delta over this long time frame, it was still possible to produce a satisfactorily calibrated model. In addition, the lack of regular time series of measurements was not insurmountable – model calibration was generally good at a monthly time scale despite large regions and time spans without sufficient data.

Increasing the complexity of the model might increase its ability to model a specific situation, but the increase in the number of required parameters will necessarily result in greater uncertainty in the model results unless accompanied by a supporting data framework. The ability to forecast Delta conditions could decline due to the greater level of uncertainty.

The weaknesses in QUAL's nutrient formulation are shared somewhat with many of the models in use at present (Edelfeldt and Fritzen, 2008; Kazezyilmaz-Alhan et al., 2007). One clear weakness discussed in several sections of this report is the constraint of setting all meteorological parameters globally. Wind speed in particular can strongly influence water quality conditions for many constituents, not just temperature.

Another weakness is the limitation to a single algal group. The discussions with Pat Gilbert highlighted the need to incorporate additional equations to simulate more than one algal group. Different species of algae will utilize nutrients differently, for example, temperature-dependent growth rates will vary across species and there are differences in preferred habitat (e.g., water column vs. substrate, still water vs. flowing water). In addition, bacteria have a large influence on nutrient dynamics, but there is no clear mechanism to capture their overall effects in the model as they do not appear as biomass in any equation. Setting decay rates for some of the constituents partially compensates for this lack.

Pat Gilbert also addressed the question of whether the current conceptual model is adequate to characterize the inhibitory effect of too much ammonia. Gilbert suggested that it is not the absolute concentration that dictates utilization of ammonia over nitrate by some algae (e.g., Dugdale's inhibitory level), but instead the relative availability of the nutrients. The current model formulation allows for a preference factor between ammonia and nitrate expressed as a ratio, which she suggested should be sufficient once the algal species that are present have been determined. On the topic of phosphate levels, she felt the implications for the limitation on algal growth due to low phosphate concentrations are not clear-cut, so there was no driving need evident for changes to the model formulation for this nutrient limitation.

Although the current conceptual formulation that models the dynamics of organic matter is somewhat standard, the lack of measurements of two components – CBOD/BOD and organic-P – meant the ability to model a large portion of the nutrient dynamics was missing. This is a combined problem of lack of measurement and lack of a suitable concept to model the measurements that exist.

Finally, the model does not track mass efficiently. It is theoretically possible to account for all sources and sinks of mass in a nutrient model, but it is not possible in QUAL. As a consequence, it is therefore not possible to utilize QUAL's fingerprinting capabilities for nutrients.

13.2 Areas for Model Development

As mentioned above, the simplicity of QUAL's nutrient formulation was generally a strength in its ability to model the entire Delta over the long time frames considered here. While inclusion of more complex dynamics may improve the ability to conceptualize a greater range of systems, it requires a commensurate level of increase in data collection to support the increased complexity.

13.2.1 Temperature/meteorology

As discussed several times, meteorological input needs to be regionalized – set locally rather than globally – to capture the range of conditions found across the Delta, particularly wind speed.

Water temperature proved to be very sensitive to heat loss due to evaporation. In QUAL, surface heat conduction, Q_e, is a function of wind speed, $f(W)$, e_s and e_a (saturation vapor pressure and water vapor pressure, respectively) and a constant C (specific weight of water times the latent heat of vaporization):

$$Q_e = C*f(W)*(e_s - e_a)$$

Note that e_s and e_a are functions of surface water temperature, air temperature and wet bulb temperature. The formulation for the wind speed function, $f(W)$, is given by:

$$f(W) = a + bW$$

where W is wind speed, assumed measured at 2.0 m height and a and b are empirical coefficients that are used to calibrate the effects of evaporation.

There are other formulations available for the effects of wind on water temperature (Cole and Wells, 2008). During the calibration process, it was found that the available parameters were not quite sufficient for capturing heat loss during summer periods. Instead, the effects of wind were increased during warm periods - in the Delta summer winds generally increase in the afternoon. This indicates that the following formulation (Cole and Wells, 2008) may be more appropriate:

$$f(W) = a + bW^C$$

where c is another empirical coefficient, assumed in (Cole and Wells, 2008) to be 2. If set to a value greater than 1, evaporative cooling would increase with wind speed which might be sufficient to capture decreased water temperature (increased evaporative loss) in the summer.

13.2.2 Algae, bacteria and plant growth

An important extension to the model would be the ability to simulate the dynamics of multiple algae species, or more generically, multiple low-level consumers and producers. In a practical sense, incorporating more than one equation for algae is no more difficult than incorporating multiple equations to model algal species, or for other producers and consumers low in the food web. This statement incorporates the discussion on mass balance, where as mentioned in Sections 13.2.and 13.2.4 below, bacteria are active in the dynamics of the system but their mass is not accounted for in the model formulation.

There are also primary producers in or at sediment level that participate in nutrient dynamics that are not accounted for, such as aquatic plants. Sediment dynamics are represented in a rudimentary manner and inclusion of macrophytes and benthic algae as individual entities would help capture the actual dynamics in some regions of the model. Some researchers have included macrophytes in a rudimentary manner consistent with the current formulation in QUAL (Park and Uchrin, 1997).

13.2.3 Other Benthic interactions

The current model formulation does not adequately allow for the effects of clams – *Corbula* and *Corbicula* in particular – that are currently believed to be causing problems at the base of the food web. Although it is would be difficult to include the biomass of clams (i.e., it would be difficult to include clam biomass as a state variable), it is possible to include their effect nutrient dynamics as rate coefficients. Salinity and temperature would need to be incorporated in the rates, as discussed in Section 12.9.

13.2.4 Mass Balance and Organic Matter

A basic problem with the nutrient formulation in QUAL, as in many nutrient models, is the lack of closure in mass balance. There are several contributions to this problem – CBOD, ignoring mass of other primary producers ,and lack of mass balance in the sediment. CBOD is ill-defined as it does not account for all biodegradable organic matter (Shanahan et al., 1998). The value for CBOD changes with the source of the material – so rates of CBOD consumption and biomass consumed can vary widely (Shanahan et al., 1998).

In addition, calculating a mass balance for the state variables requires that mass losses and gains to sediment must be properly accounted for. Because the SOD losses are not tied to CBOD mass loss or gain, mass balance overall cannot be accounted for.

Although bacteria mediate the loss rates for constituents through decay rates, their biomass is also ignored. Bacteria would need to be treated as a state variable, similar to algae, with an equation describing the movement of mass into and out of the water column as a function of the rate coefficients.

There are disaggregated formulations in nutrient models (Cole and Wells, 2008) for the representation of organic matter and CBOD – representing, for example, “fast” and “slow” reacting CBOD (Shen et al., 2002) and/or dissolved and particulate labile and refractory organic matter for both N- and P-fractions. Using the labile and refractory split for organic matter requires eight equations (Cole and Wells, 2008), plus measurements and rate parameters to support the dynamics of these refined nutrient interactions.

13.3 Discussion

Of the areas for development discussed above, only a few are important to improve the representation of nitrogen dynamics given the available data. Clearly, improving the representation of meteorology through regionalization is a straightforward fix that is necessary if the model is to be used in a predictive manner if Delta-wide water temperature is important in a given study.

Including a refined level of state variables at the base of the food web – additional algal species and more than one species of bacteria – would increase the ability to capture the consumption and production of N-constituents at the expense of additional data gathering requirements. However, an improved formulation and additional data acquisition would address the central questions of this study on the role of ammonia in nutrient dynamics, and if hig140

h concentrations are suppressing algal growth.

Refining the model sufficiently to attain a set of state variables that each observe a mass balance and describe both the water column, pelagic and benthic interactions is an ideal goal, but would require a rewrite of the entire model.

1. Including additional reaction rates for nutrient sinks and sources for teasing out the effects of *Corbula* and *Corbicula* would allow a better representation of the nutrient sinks in the Delta (Jassby 2008). This could be approached by tying reaction rates to salinity (and potentially other state variables) without requiring a strict mass balance, similar to the approach currently used for bacteria. Or, the biomass of clams could be included in a more rigorous

fashion through a set of equations conceptualizing generic benthic inhabitants in which a mass balance for the system is better approximated than at present.

Some models have simplified the representation of P-constituents (Shen et al., 2002), which might work well in this system, given the lack of organic-P measurements available in the Delta.

Although the effect of pH may be important in specialized situations, the current study did not find an overwhelming need to include pH-dependence in the reactions, as equilibrium calculations indicated that under typical conditions in the Delta, ammonia will be generally found in its ionized form as NH_4^+. In addition, the system will be outgassing CO_2 as biotic activity overwhelms atmospheric contributions of CO_2 so pH buffering by the atmosphere is generally not a driving force in the dynamics.

Macrophytes and Submerged Aquatic vegetation (SAV) may be important in Delta nutrient dynamics, but their effect was not evident in the current study, perhaps because the focus was on the Sacramento River corridor, and not on the central and south Delta.

14 Monitoring program

Two considerations dominate the definition of a monitoring program – frequency of measurement and spatial density of measurement locations. In the current modeling effort, it was mainly the time scale of the data (monthly-irregular) that dictated the accuracy of the results, although there were two regions of the model where data coverage was clearly insufficient. Despite these constraints, the data available for developing the model was generally sufficient for the task of modeling nutrient dynamics with a focus on ammonia on a monthly time scale.

The third consideration is cost – that constraint is not explicitly considered here, other than in the evaluation of priorities. EC monitoring is not included in this section, as the Delta salinity monitoring program is quite extensive and not in need of overhaul in order to improve the modeling of nutrient dynamics.

14.1 Current/past data gathering efforts

Generally, the quality of data considered in this report (generally from publically funded sources) was better in recent years (2000 –present), while geographical coverage was better historically (1990 – 1995). Sections 6 - 8 cover the current data set, from data sources, availability to use in setting boundary conditions. Section 17.2 in Appendix 1 details all of the data sources and the frequency of measurement for each of the modeled constituents.

14.1.1 Data Coverage

There are three regions in the model domain where the spatial density of data was most problematic – in the Yolo/Cache area in the northeastern Delta, and in Suisun Marsh (Figure

17-18). There were measurements available in the south and central Delta, but the spatial coverage was low and the time span was not consistent. There was insufficient data available at the northernmost boundary of the model (see Section 8.4.1.1) particularly for N-constituents, although this difficulty was not critical as there were downstream measurements available to help develop the Sacramento R. boundary condition.

The situation was somewhat better for temperature modeling, although the same areas (Suisun Marsh and the Yolo/Cache Slough area) were clearly deficient in spatial data density. The density of in-Delta measurements and the number of measurements available for calibration and validation were sufficient to produce a Delta-wide temperature model. However, there is the proviso that meteorological boundary conditions need to be regionalized in the numerical model, so the calibration in the north Delta is superior to the results in the south Delta.

As discussed in previous sections of this report, there were two constituents, organic-P and CBOD, that did not have sufficient data available to calibrate the model parameters with any confidence.

14.1.2 Sufficiency for Ammonia/temperature modeling

The availability of N-constituents, including ammonia, was better than for other constituents, so the data were sufficient for developing a model with accuracy up to a monthly time scale. The EMP has a long-term dataset that includes several measurement locations in the Delta and at or near the model boundaries, and the main sources of N-constituents from waste water, near Stockton and Sacramento, each had data sets with most constituents that covered most of the 19-year modeled period. The smaller waste water treatment facilities had mixed coverage. Sections 7.7.2 and 14.1.1 discuss the availability of temperature data, which was sufficient for validation and calibration. Section 7 has detailed descriptions of the data available for defining the model boundaries and for calibration.

14.2 Suggested Monitoring Regime for the Current Conceptual Model

This section covers suggestions for a monitoring program under the assumption that the scheme will be used in the current model formulation, and that measurements should be taken for each of the modeled constituents.

14.2.1 Temporal coverage

The desired temporal coverage depends somewhat on the demands of the modeling effort –a model aiming at temporal scale on the order of months requires fewer data points than a model hoping to capture diurnal or tidal variations. Table 14-1 gives a listing of the suggested timing for the measurement of the primary model constituents, other than EC, with a coarse breakdown by desired temporal accuracy under the assumption of a daily accuracy requirement (approximately).

For water temperature modeling, because instrumentation is relatively simple to maintain and it can be placed in-situ, the suggested measurement frequency is hourly and at a minimum daily. Meteorological measurements are generally taken at least hourly.

If a special study were to be developed, then tidal timing and measurement frequency would need to considered together, under the assumption that the more difficult or costly measurements would be taken sporadically at a higher frequency, and most likely at a finer spatial scale. Occasional high frequency measurements (several times a day) are important for teasing out tidal effects and day/night fluctuations in dynamics.

14.2.2 Spatial/Regional coverage

Figure 14-1 through Figure 14-4 illustrate suggested sampling locations for an enhanced monitoring scheme, with lesser priority locations indicated by yellow stars. Ideally, for most of the nutrients, all locations would be sampled. The new monitoring locations cover areas that appear to important dynamically in the model (Cache Slough, Jersey Point) or because they are near model boundaries (Figure 14-1) or in major channels or sloughs (for example, in Suisun Marsh, Figure 14-3).

14.2.3 Supplementary measurements

Full sets of water analyses at monthly or weekly intervals are valuable in providing a detailed view of the water chemistry, For example, in this report R. Dahlgren's dataset was used to develop EQ3/6 geochemical models that helped define aspects of the system's water chemistry such as level of biological activity.

Pat Gilbert and others recognized the need to distinguish between algal species and bacteria utilizing and transforming the nutrients. Although the current model formulation only allows for one algal species, one suggested improvement to the conceptual and numerical models is the inclusion of multiple algal and bacterial species. This would require additional measurements as a high priority.

Currently, measurements of biological activity in the sediment are not available. Although the model concept for sediment interactions is currently rudimentary, the lack of information to inform parameters utilized in the sediment dynamics was a drawback.

14.3 Priority measurements

Each of the modeled constituents needs to be measured, including CBOD and organic-N which are not currently measured. The frequency should be at least at the desired temporal accuracy in Table 14-1, under the assumption that a model with daily temporal accuracy should be developed. Of the locations identified as higher priority in Figure 14-1 through Figure 14-4, the Yolo/Cache region and the north Delta (Sacramento River model boundary through Georgiana

Slough) are the most important areas to obtain supplementary measurements for ammonia dynamics in the current study.

14.4 Monitoring for an Improved Conceptual Model

Organic matter can be more or less bioavailable, and the current model does not allow the disaggregation of organic materials. A major improvement to the conceptual model would be an improved methodology for the dynamics of organic matter consumption and production. This would require an extensive collection regime for organic data measurements.

Table 14-1 Basic temporal measurement scheme for the current nutrient model.

Location	Constituent	Desired Temporal Accuracy	Measurement Frequency	Max/Min	Special Study
Inflow/outflow Boundary	Water temperature	hourly	hourly		several times/day
	All meteorlogy	hourly	hourly		
	Flow	hourly to daily	hourly to daily		
	Ammonia	Daily	Daily to several times/wk		several times/day
	Nitrate	Daily	Daily to several times/wk		several times/day
	Nitrite	Daily	Daily to several times/wk		several times/day
	CBOD	weekly	weekly		daily
	DO	hourly	hourly		hourly
	PO_4	Daily	Daily to several times/wk		several times/day
	Chl-a/POM	Daily to several times/wk	Daily to several times/wk		several times/day
	TKN or Organic-N	Daily to several times/wk	Daily to several times/wk		several times/day
	Organic-P	several times/wk	several times/wk		daily
In-Delta/Receiving Water	Water temperature	12 hour	hourly	daily	
	All meteorlogy	hourly	hourly	daily	
	Flow	6 hour	Hourly to daily		
	Ammonia	Daily	Daily to several times/wk		several times/day
	Nitrate	Daily	Daily to several times/wk		several times/day
	Nitrite	Daily	Daily to several times/wk		several times/day
	CBOD	weekly	weekly		daily
	DO	hourly	hourly		hourly
	PO_4	Daily	Daily to several times/wk		several times/day
	Chl-a/POM	Daily to several times/wk	Daily to several times/wk		several times/day
	TKN or Organic-N	Daily to several times/wk	Daily to several times/wk		several times/day
	Organic-P	several times/wk	several times/wk		daily
Effluent	Water temperature	12 hour	hourly	daily	
	Flow	6 hour	hourly to daily	daily	
	Ammonia	12 hour	12 hour		
	Nitrate	daily	daily		
	Nitrite	weekly	weekly		
	CBOD	weekly	weekly		
	DO	daily	daily		
	PO_4	daily	daily		
	Chl-a/POM	monthly	monthly		
	TKN or Organic-N	several times/wk	several times/wk		
	Organic-P	weekly	weekly		

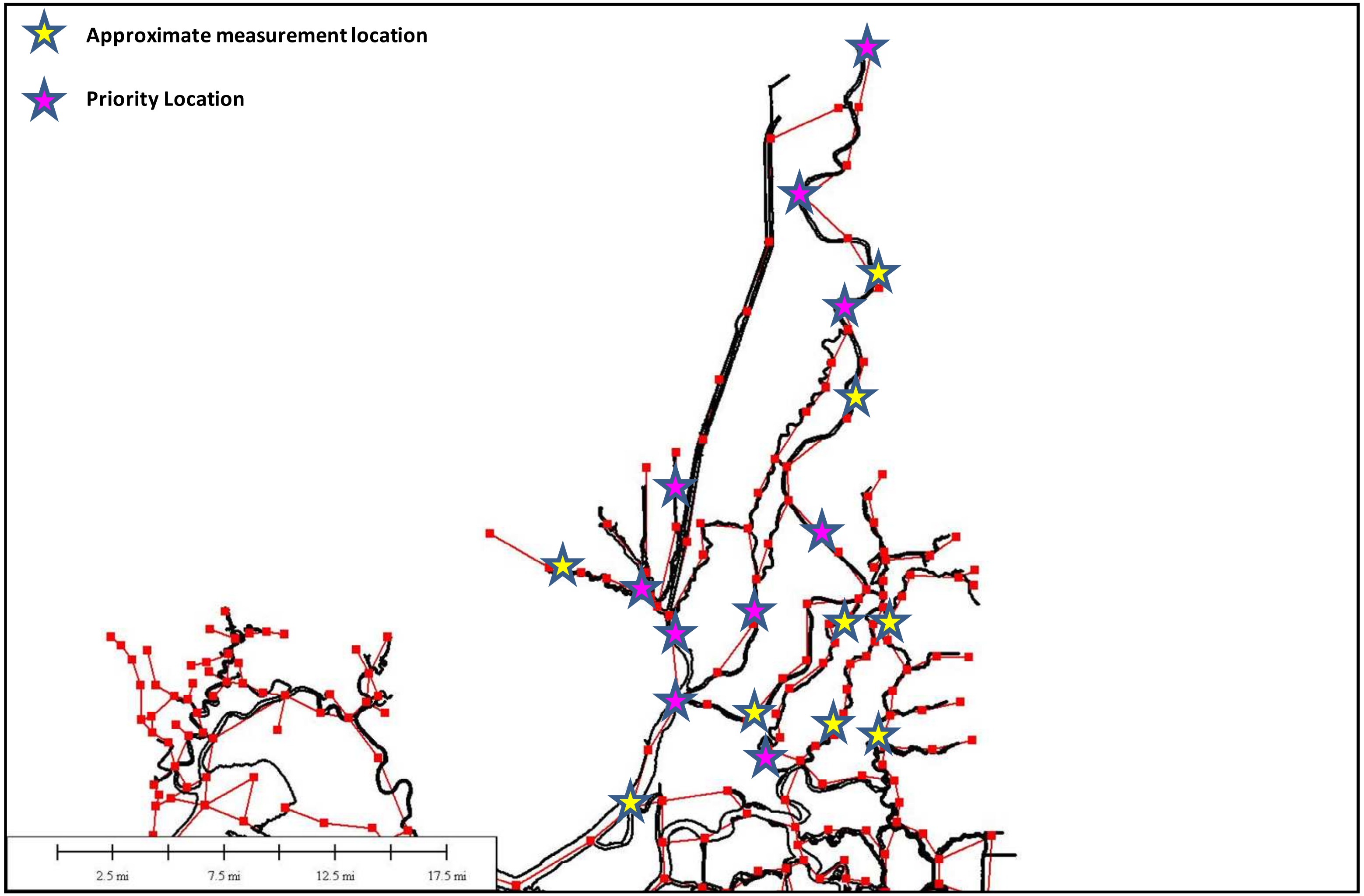


Figure 14-1 Suggested and prioritized locations for an enhanced nutrient monitoring scheme in the north Delta.

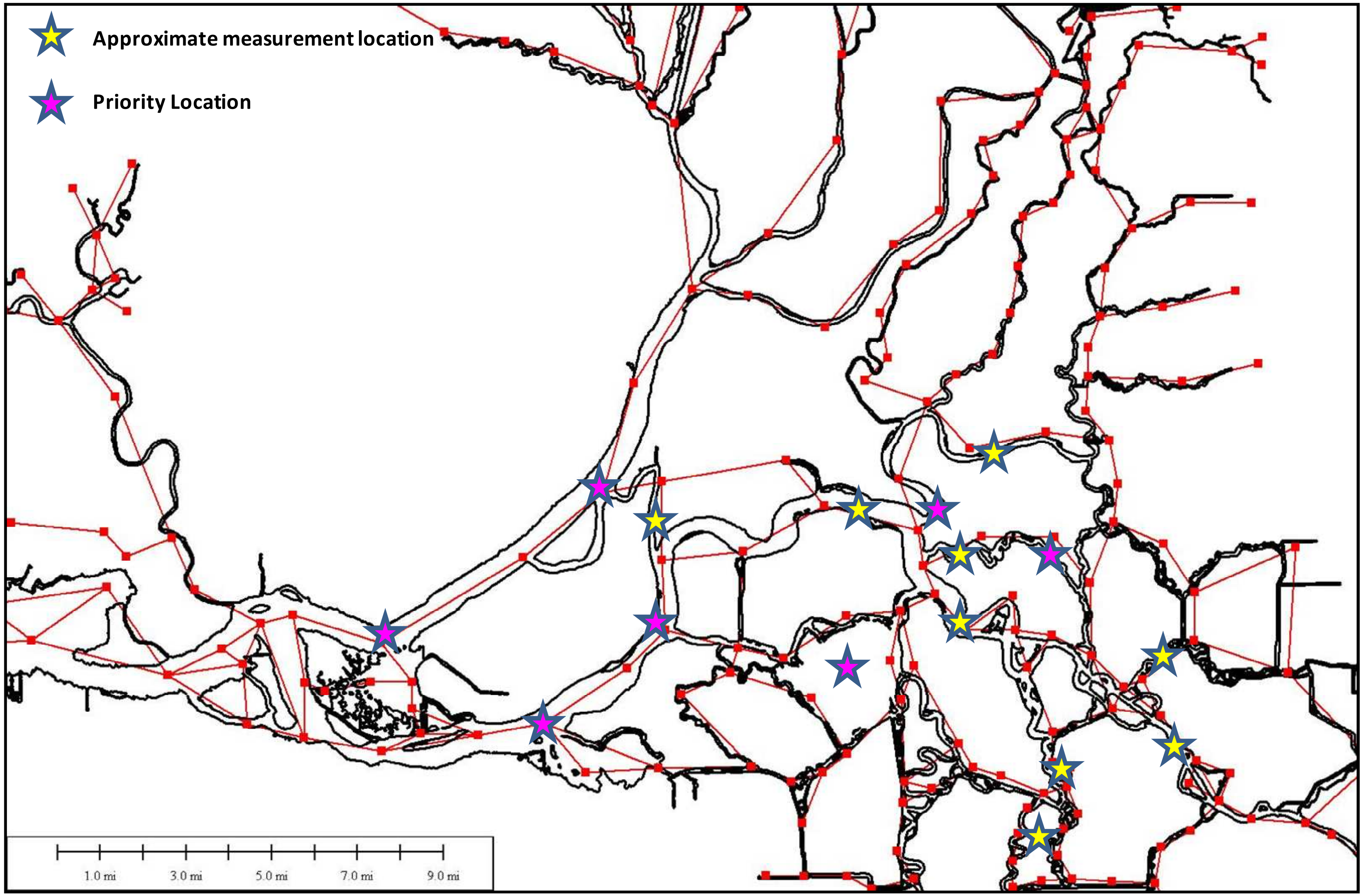


Figure 14-2 Suggested and prioritized locations for an enhanced nutrient monitoring scheme in the eastern Delta.

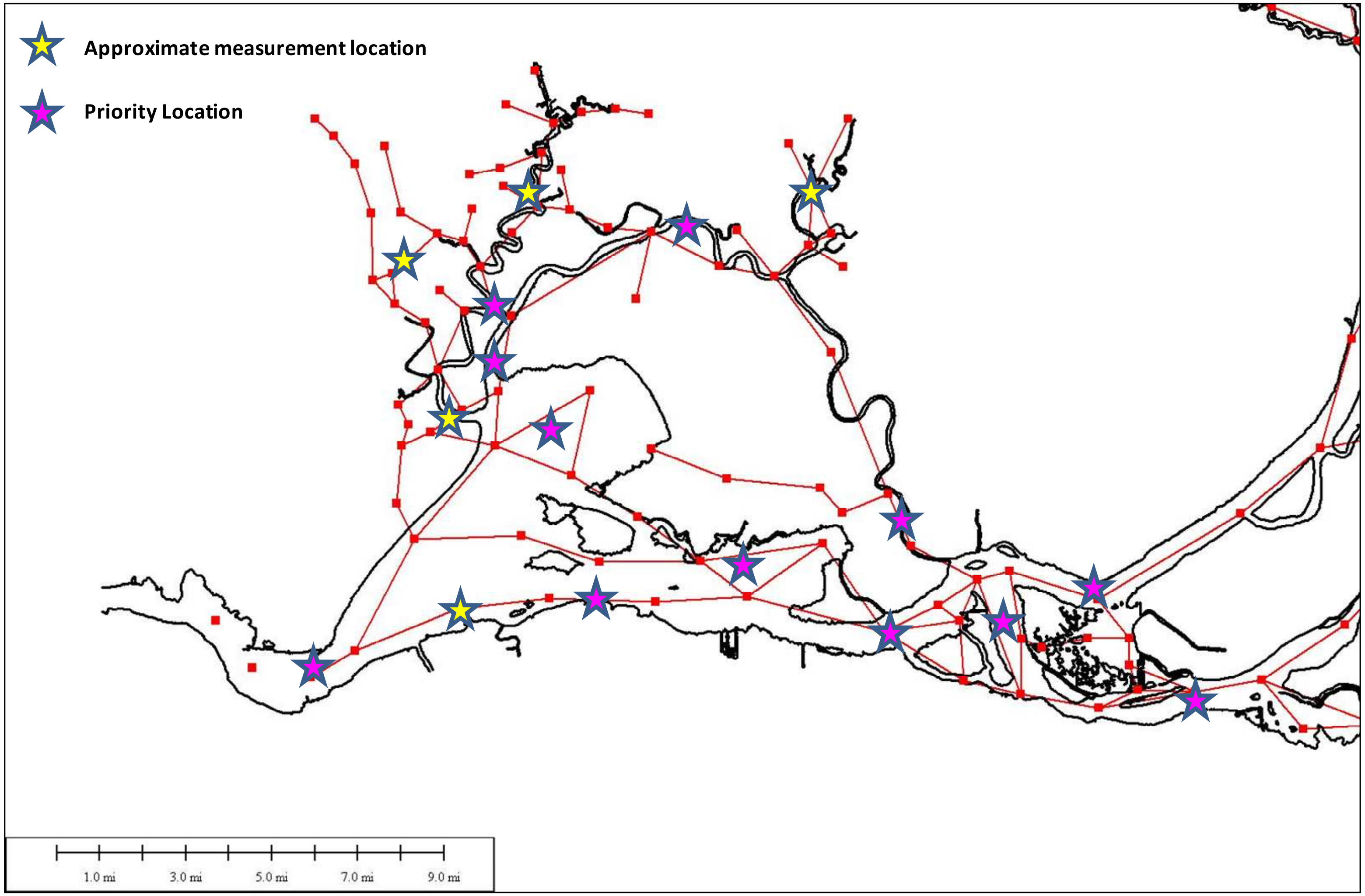


Figure 14-3 Suggested and prioritized locations for an enhanced nutrient monitoring scheme in the western Delta.

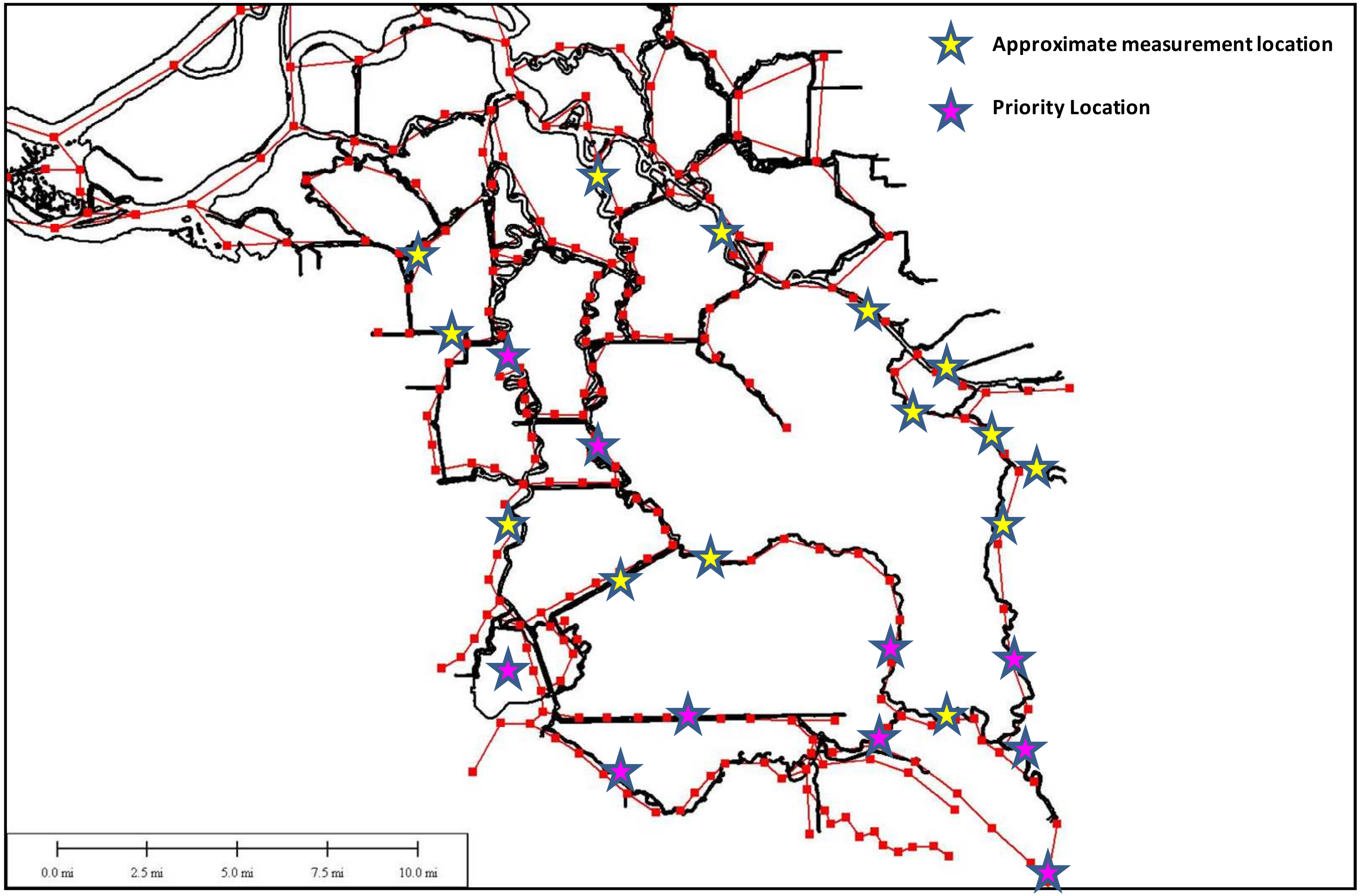


Figure 14-4 Suggested and prioritized locations for an enhanced nutrient monitoring scheme in the south Delta.

15 Summary and Conclusions

DSM2-QUAL was calibrated for water temperature and nutrients, with a focus on ammonia dynamics. Calibration and validation statistics indicate that the model calibration is very good for temperature along the Sacramento River corridor and the lower San Joaquin River, and good but biased to cooler-than desire temperatures in the south Delta and at upstream locations on the San Joaquin River.

The nutrient model in DSM2, QUAL, has a simple conceptual formulation that proved sufficient for the task of modeling a long time frame, 1990 – 2008, over the entire Delta. The frequency of boundary conditions for the nutrients, essentially monthly, dictated the level of accuracy in model results. Calibration for the N-constituents was generally very good, except at a few locations. Calibration for the P-constituents was not as good, as organic-P measurements are not available to help constrain those constituents. In areas where there were few or no measurements, boundary conditions were set at reasonable levels to maintain calibration at downstream locations.

The Yolo/Cache area appears to be important locally near Rio Vista and downstream to the confluence. The inclusion of new flow data at the Lisbon Toe Drain had a noticeable influence on nutrient dynamics and on volumetric contributions around Rio Vista and at downstream locations. Inclusion of a flooded Liberty Island in the DSM2 grid generally increased algal biomass at downstream locations and decreased concentrations of N-constituents.

One improvement in the model that would help in studying nutrient dynamics for ammonia is the inclusion of multiple algal groups, and an enhanced formulation for bacterial dynamics (most likely the inclusion of new constituent relationships). The model formulation proved inadequate to capture the effect of clams (*Corbula* and *Corbicula*). There are several possible approaches for improving the conceptual model to capture their effects on the food web. The most difficult area to improve in the model is the treatment of organic materials. Most changes would require a major overhaul of the conceptual model.

Although the data were sufficient to develop a nutrient model focusing on ammonia dynamics, there are several ways in which the monitoring programs should be improved. First, some model constituents are not measured (organic-P and CBOD), which becomes a problem in P-constituent dynamics. Next, some regions of the model do not have any coverage, and some areas have marginal coverage. The Yolo/Cache area and portions of the eastern Delta need measurement locations as there are currently none. Next, Suisun Marsh and the central Delta could use measurement locations, as most of the data that currently available ends in 1995. Ancillary measurements should be taken along with the main constituents at infrequent intervals. Full sets of chemical analyses sufficient to develop geochemical (thermodynamically-based) models help clarify the driving processes. Also, measurements to distinguish between dominant algal species and bacteria would help clarify the dynamics, and could inform an improved conceptual model in QUAL. Finally, sediments should be sampled to analyzed possible contributions to nutrient dynamics from resident algae or marcophytes.

A sensitivity study of the model to increases and decreases in N-constituent concentrations for DICU, at the Sacramento and Joaquin Rivers, and for the Sacramento and Stockton WWTP's was completed. Changing the Stockton WWTP concentrations had only minor effect, mainly in nitrate concentration. The effects ceased at Twitchell Island. Similar results were seen in changing the concentrations at the San Joaquin boundary, although the effects persisted past Jersey Point.

Changing concentrations at the Sacramento River boundary produced changes in nitrite concentration which were largest in drier years, while nitrate concentration changes were largest in wetter years. Changes persisted past Potato Point into the lower San Joaquin and to a small degree into the Suisun Bay area. Changing N-constituent concentrations at the Sac Regional WWTP had a larger effect. The changes in N-constituent concentration downstream of the Sac Regional WWTP were large and sustained along the Sacramento R. corridor to Suisun Bay. Ammonia and nitrite concentrations showed the largest shifts. Algal biomass increased or decreased to small degree as effluent-N increased and decreased.

A scenario was developed in which Sac Regional WWTP operations were switched to nitrification. As expected, concentrations of ammonia decrease and nitrate increase. Nitrite shows large decreases at all locations which are apparently linked to the ammonia decrease. The dynamics are complicated, and in some cases, there is a shift in the timing of high points and low points in concentration particularly for nitrate. Algal growth is inhibited somewhat, with a few exceptions in wetter years.

16 Next Steps

The following suggestions highlight possible areas for extending the results of the current study.

16.1 Extending Model to Current Day

The Historical nutrient model ends Dec. 31, 2008, but there are new sets of high quality nutrient measurements available to extend the nutrient model results through July. Boundary conditions for HYDRO and QUAL-EC are also available.

As discussed at the "Ammonia Summit", several groups and agencies have recently undertaken extensive nutrient measurements in the investigation of ammonia issues. These measurements are available for use to further our understanding of nutrient dynamics, and as an additional means of assessing and improving model definition. These data remove some of the major problems with the historic data – the spatial density of measurements is much higher, measurements have been taken in the critically important Yolo/Cache area, and measurements have been taken at a higher temporal frequency to allow for assessment on a fine time scale (less than daily). Because overlapping measurements have been taken by several parties, the uncertainty in the data and model can be minimized.

16.2 Publication

With some additional work, the effort undertaken for this report can form the backbone and a major portion of the work required for producing a publication in a peer-reviewed journal. A refinement of some aspects of the model calibration should be completed. For example, it is possible to develop return values for mass currently lost at the Martinez boundary due to tidal activity. A refinement of the Yolo, and Sacramento and San Joaquin River boundary conditions could improve the downstream results of some constituents. Although much work has been completed (summarized in this report), the analysis of the results can be deepened, and more pointedly address the issue of the sources and sinks of ammonia in the Delta. A synthesis of model results and data would greatly strengthen publication potential.

16.3 Extending Modeled Period Back to Quantitatively Assess the Effects of Corbula

The current Historical model time span begins in 1990, but the DMS in DWR has been working to extend the Historical model back to the time before *Corbula* invaded the estuary. The model calibration to date was limited by the inability to model algal dynamics without the interference of *Corbula*. Calibrating the model to a *Corbula*-free period will allow the quantitative assessment of the effect clams have had on the base of the food web in the Delta.

The EMP has been collecting measurements at many locations in the Delta since the 1970's, so there is a dataset of measurements available to use in setting inflow boundary conditions and in calibrating the model.

16.4 Uncertainty Analysis

All models are plagued by various sources of uncertainty, and there are methodologies available to capture the uncertainty in model calculations (Abrishamchi et al., 2005; Himesh et al., 2000). For example, it is possible to run a Monte Carlo analysis using DSM2/QUAL over reasonable time frames, such as several years. These model runs are sufficiently short and computing power is easily available to accommodate such analyses.

A Monte Carlo analysis could set bounds on the uncertainty of model predictions that are important to understand both in a scientific sense and in a regulatory sense.

16.5 Comparative Nutrient Model/Isotope Analyses

Although some collaboration has taken place with USGS researchers (Kendall *et al.*), there was not funding in the original scope of work to pursue a full comparative analysis of the isotope findings in the nutrient model results. DSM2 model results are useful in understanding isotope analyses, and there is great potential for constraining and analyzing modeled nutrient results.

16.6 Yolo/Cache Region and Liberty Island Recalibration

The representation(s) of the Yolo/Cache region and/or the Suisun Marsh region can be greatly improved by refining the boundary conditions and including the new Liberty model grid. The new DSM2 Liberty grid results have shown that the Yolo/Liberty/Cache Sl. area can have important effect of nutrient levels downstream of the confluence with the Sacramento R. RMA has worked extensively on the representation of this regions, so an improved set of flow boundary conditions is available for use. Additional research into nutrient data acquired by special studies would be helpful - collecting this data were an effort that went beyond the needs for this calibration report.

The Yolo/Cache region has proved particularly important in nutrient dynamics downstream of the Sac Regional effluent outfall, as recent measurements indicate the dynamics near Rio Vista are apparently heavily influenced by the tidal dynamics with the Yolo/Cache area. Improving the model representation of this region could help resolve some of the questions the measurement analyses have been posing.

Several WWTPs have effluent flowing into this region – their contributions were not included as the Liberty grid had not been finalized when the model was developed. Given the relatively large effect the region has on downstream nutrient dynamics and the large effect the inclusion of a flooded Liberty Island has on ammonia and algal dynamics, the refinement of the nutrient dynamics and inclusion of additional effluent sources should be a priority. These areas are becoming increasingly important as restoration areas, and the first step in understanding restoration potential is improving the understanding what is currently happening in nutrient dynamics there.

16.7 Suisun Marsh region

RMA has worked extensively on improving the representation of the Suisun Marsh, so an improved set of flow and salinity boundary conditions and calibration data are available for use. DWR Suisun marsh Branch has developed an improved grid in the marsh area (Kate Le, personal communication). Additional effort in obtaining nutrient data acquired by special studies would be needed, an effort that went beyond the effort required for this calibration report.

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17 APPENDIX I

17.1 DSM2 Grid

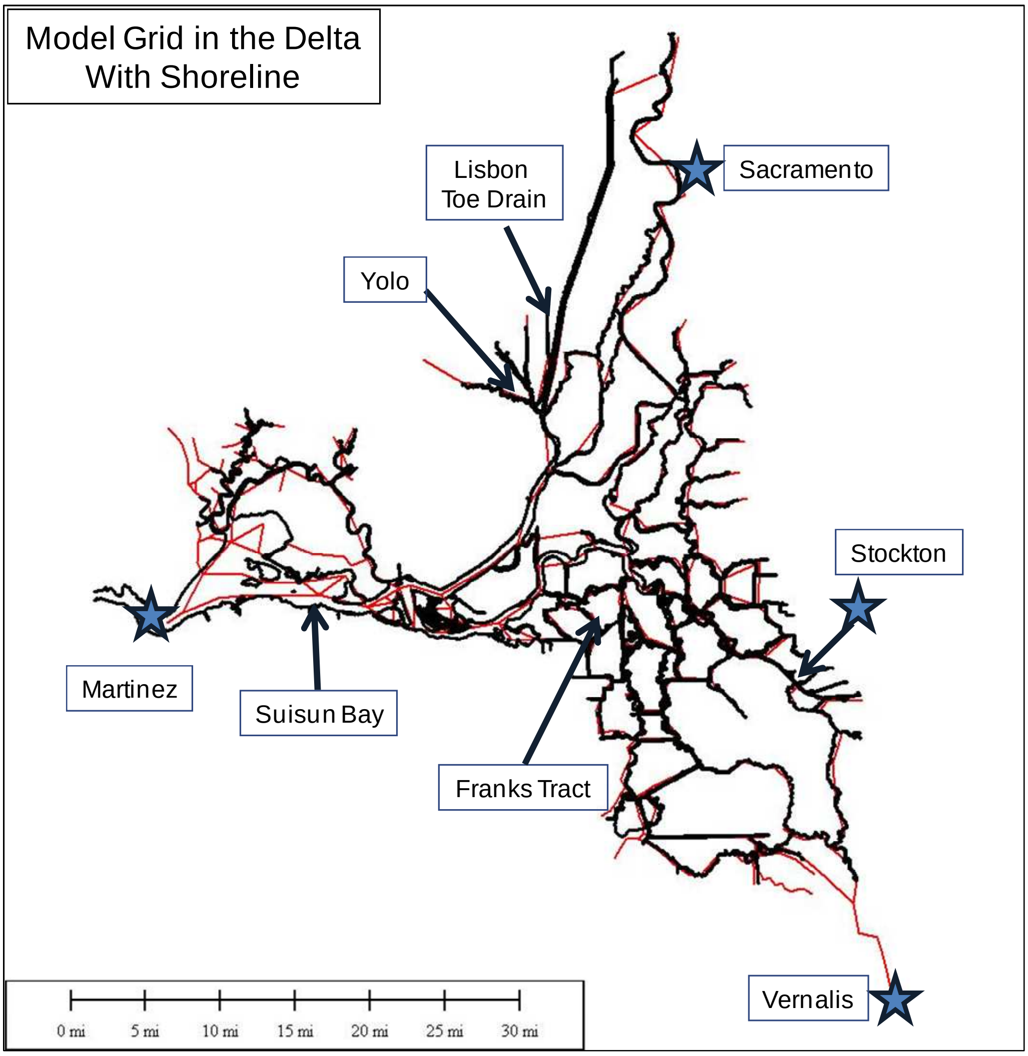


Figure 17-1 DSM2 model grid (red) with the shoreline of the Delta shown in black.

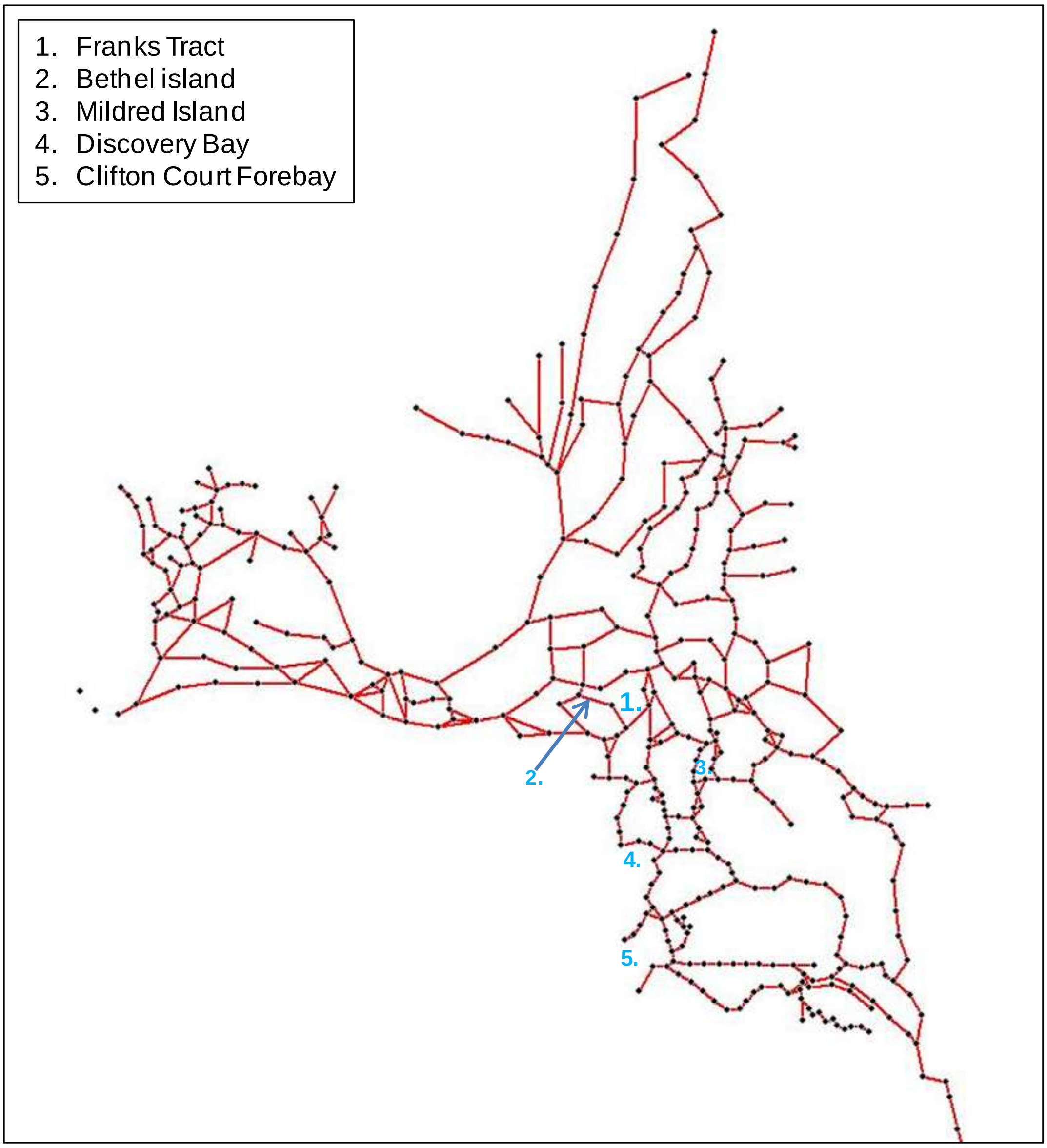


Figure 17-2 Channels (red), reservoirs (blue numbers), and nodes (black) in the DSM2 model grid.

17.2 Data Sources – Figures and Tables

Table 17-1 Data sources for effluent data and in-Delta measurements.

Effluent Data Locations	Name	Organizatiion
Sacramento Regional County Sanitation District	Robert Seyfried,Vyomini Pandya	Sac Regional
Woodland	Mark Hierholzer, Erich Delmas	Woodland
Vcacaville	Tony Pirondini	(contact only)
City of Stockton - M.U.D.	Larry Huber	City of Stockton - M.U.D.
City of Tracy	(Steven Bayley)	(contact only)
Lodi	Charles Swimley	Lodi
Manteca	Heather Grove	Manteca
Delta Diablo	Amanda Wong Roa	Delta Diablo
Fairfield-Suisun	Meg Herston	Fairfield-Suisun
CCCSD	Bhupinda Dhalewal, May Lou Esparza	CCCSD
Effluent Data - Regional Board		
Various Central Valley sources		Regional Board - Chris Foe
Various San Francisco Bay sources		Regional Board
In-Delta measurements		
Access data base for Central Valley Drinking Water Study	Elaine Archibald	CUWA
Various effluent and in-Delta measurements	Lynda Smyth - MWD	MWD
Boundary condition measurements	Randy Dahlgren	U.C. Davis
Access data base of nutrients	Mike Johnson	U. C. Davis
DICU data	Ted Swift , Bruce Agee	MWQI
2007 - 2009 nutrient data	Anke Mueller-Solger, Scott Waller	EMP

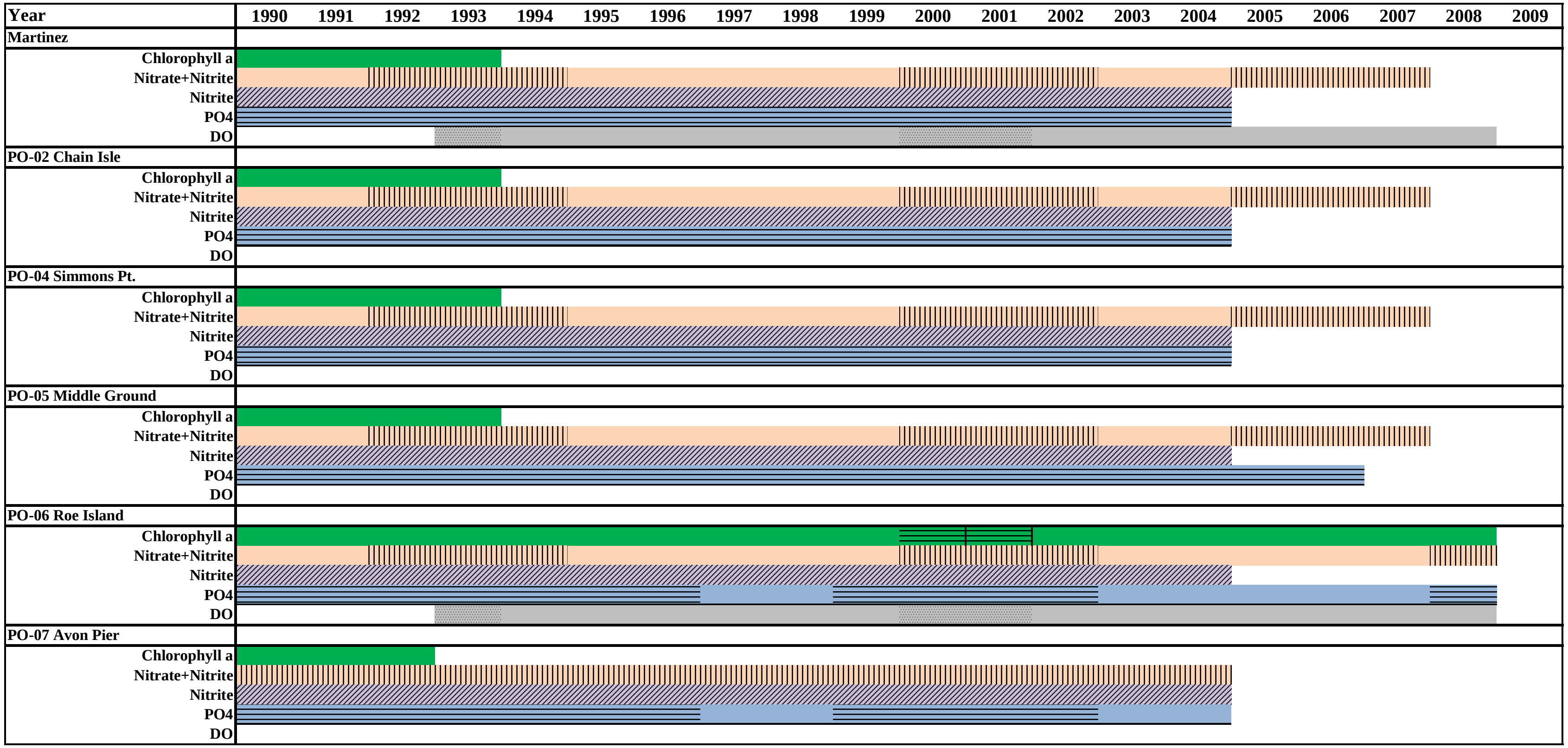


Figure 17-3Availability of USGS nutrient data at six USGS sites. Shading (hashes, dots) indicates partial year of data.

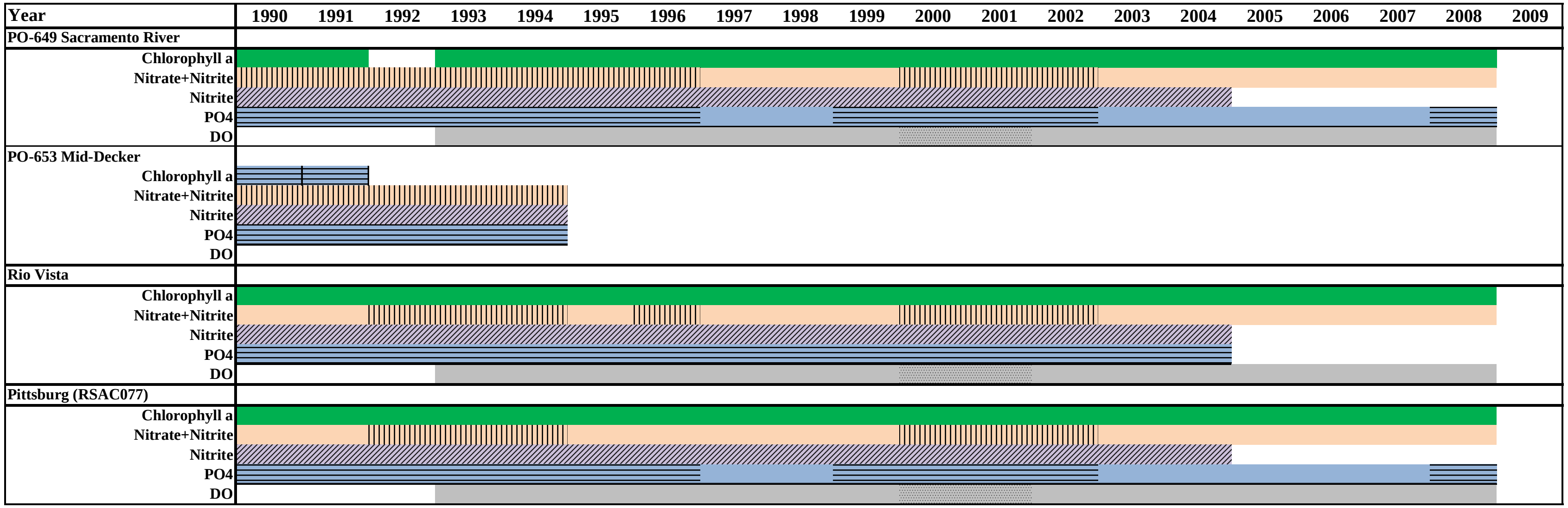


Figure 17-4Availability of USGS data at the remaining four sites. Shading (hashes, dots) indicates partial year of data.

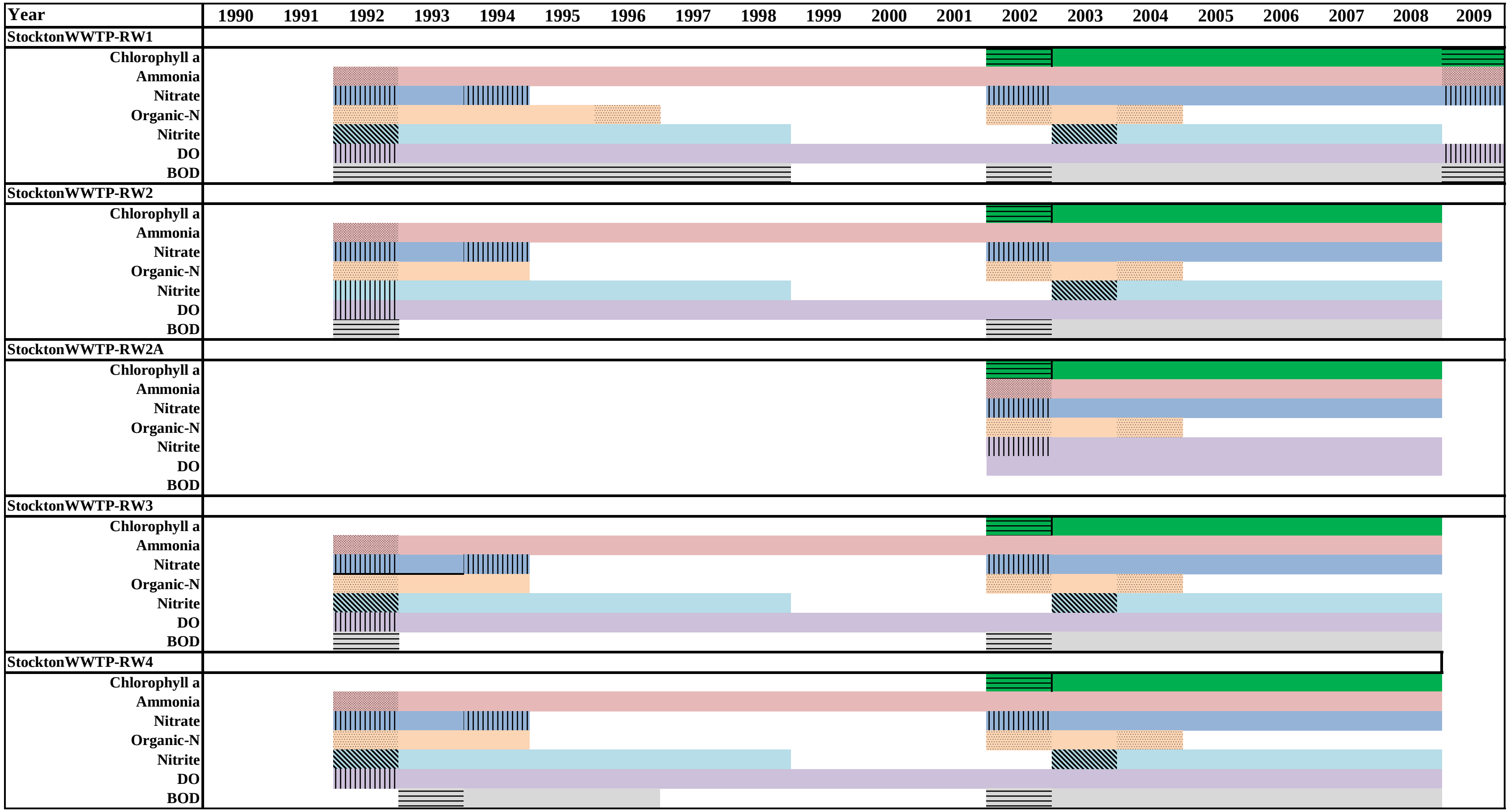


Figure 17-5 Availability of Stockton WWTP receiving water measures for sites RW-1 to RW-4. Shading (hashes, dots) indicates partial year of data.

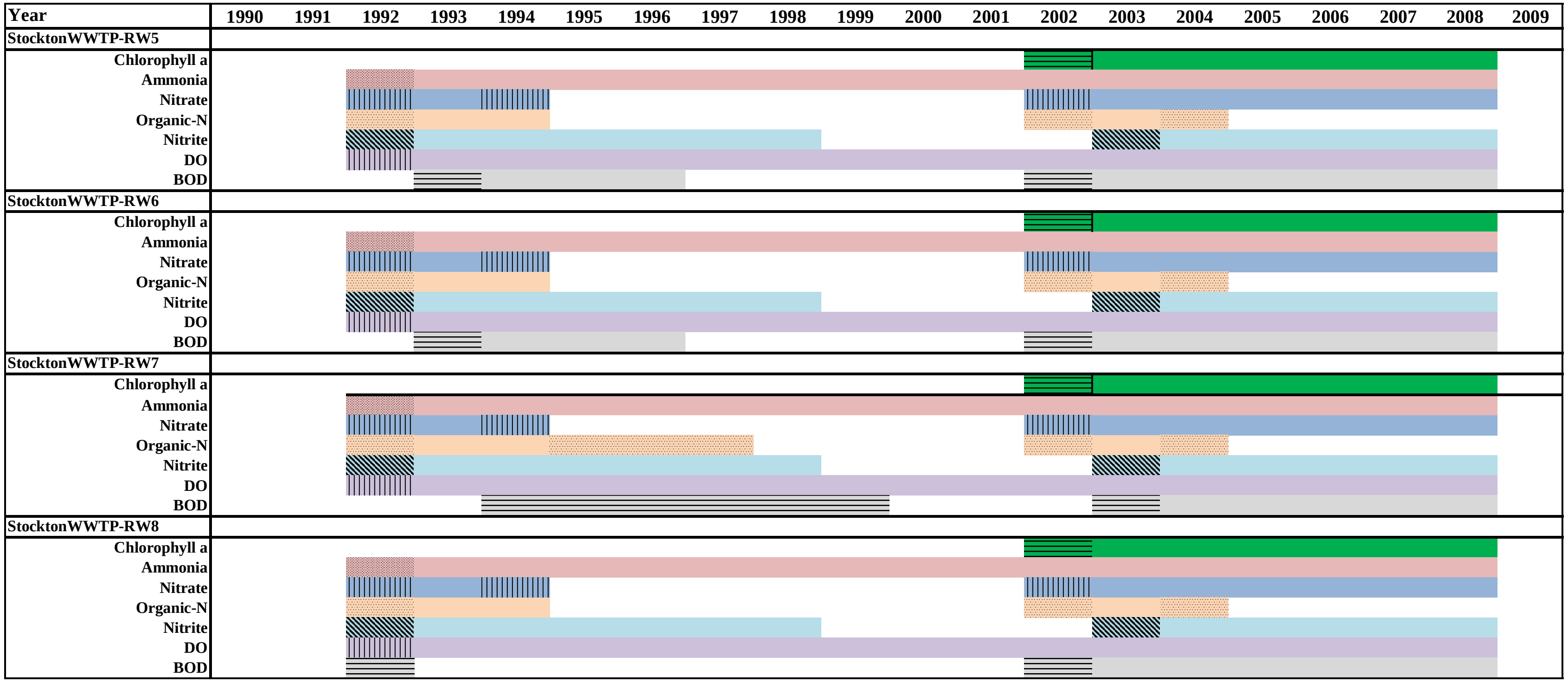


Figure 17-6 Availability of Stockton WWTP receiving water measures for sites RW-5 to RW-8. Shading (hashes, dots) indicates partial year of data.

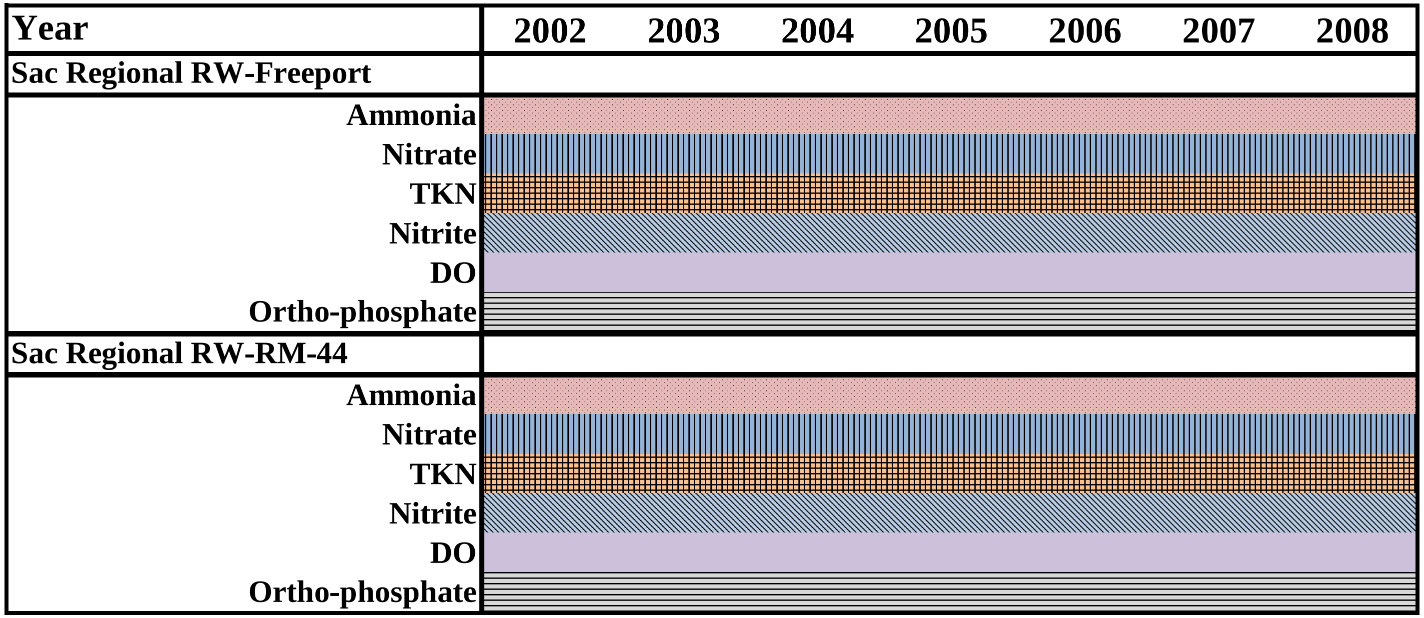


Figure 17-7 Availability of Sac Regional WWTP receiving water measurements. Shading (hashes, dots) indicates partial year of data.

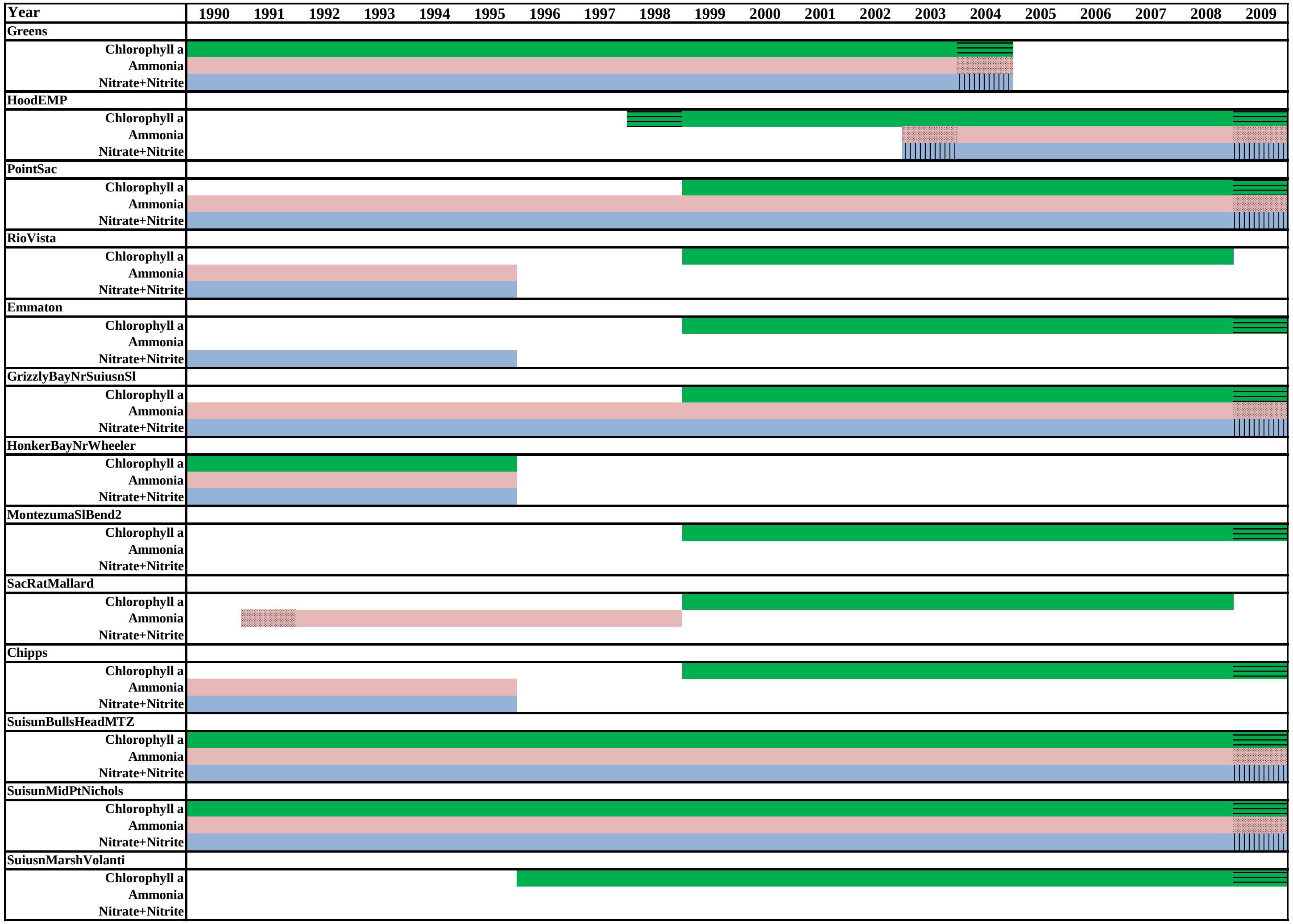


Figure 17-8 Availability of EMP/BDAT NH_3, NO_3+NO_2, and chlorophyll a measurements (Part 1). Hatching means partial-year data.

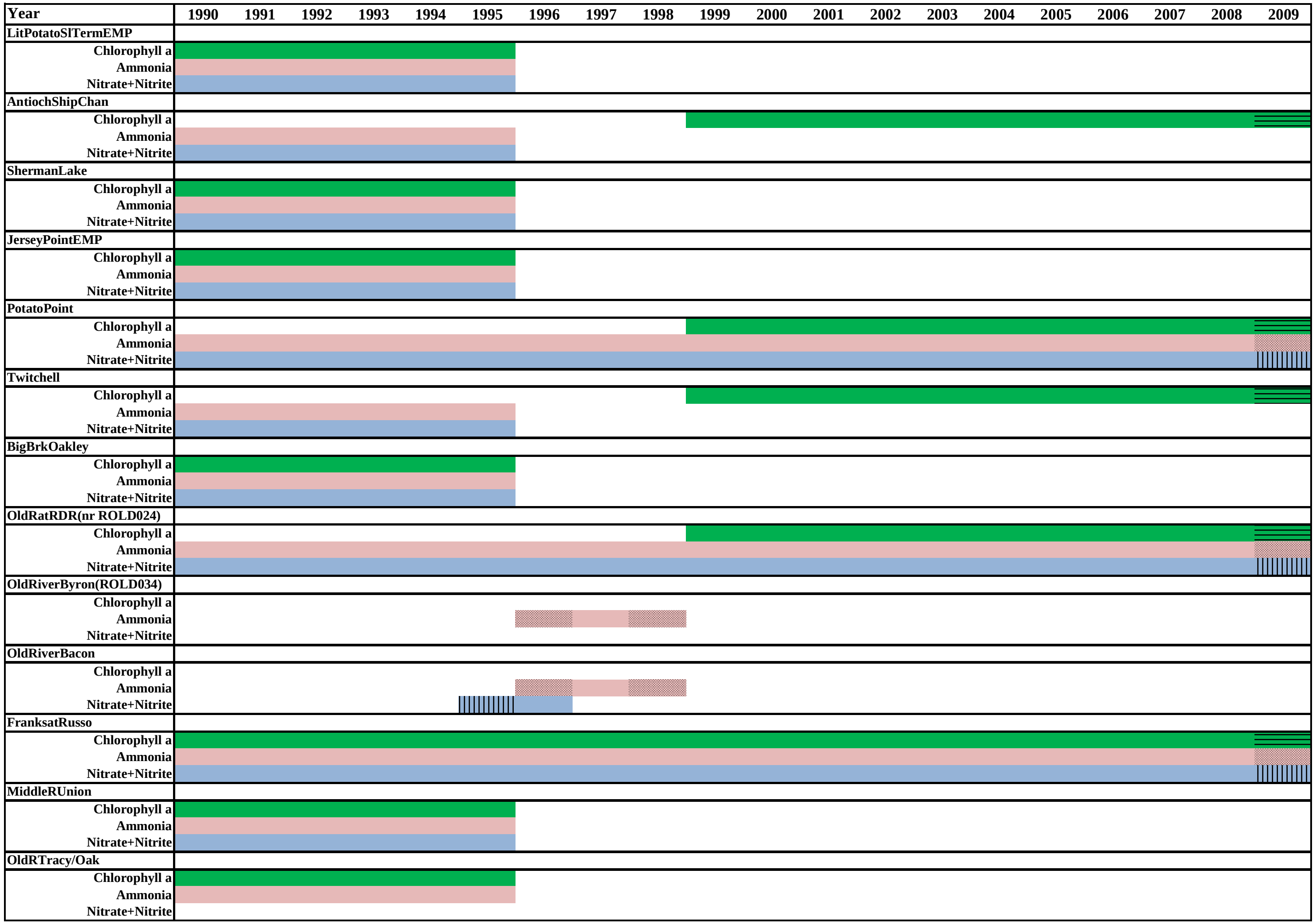


Figure 17-9 Availability of EMP/BDAT NH_3, NO_3+NO_2, and chlorophyll a measurements (Part 2). Hatching means partial-year data.

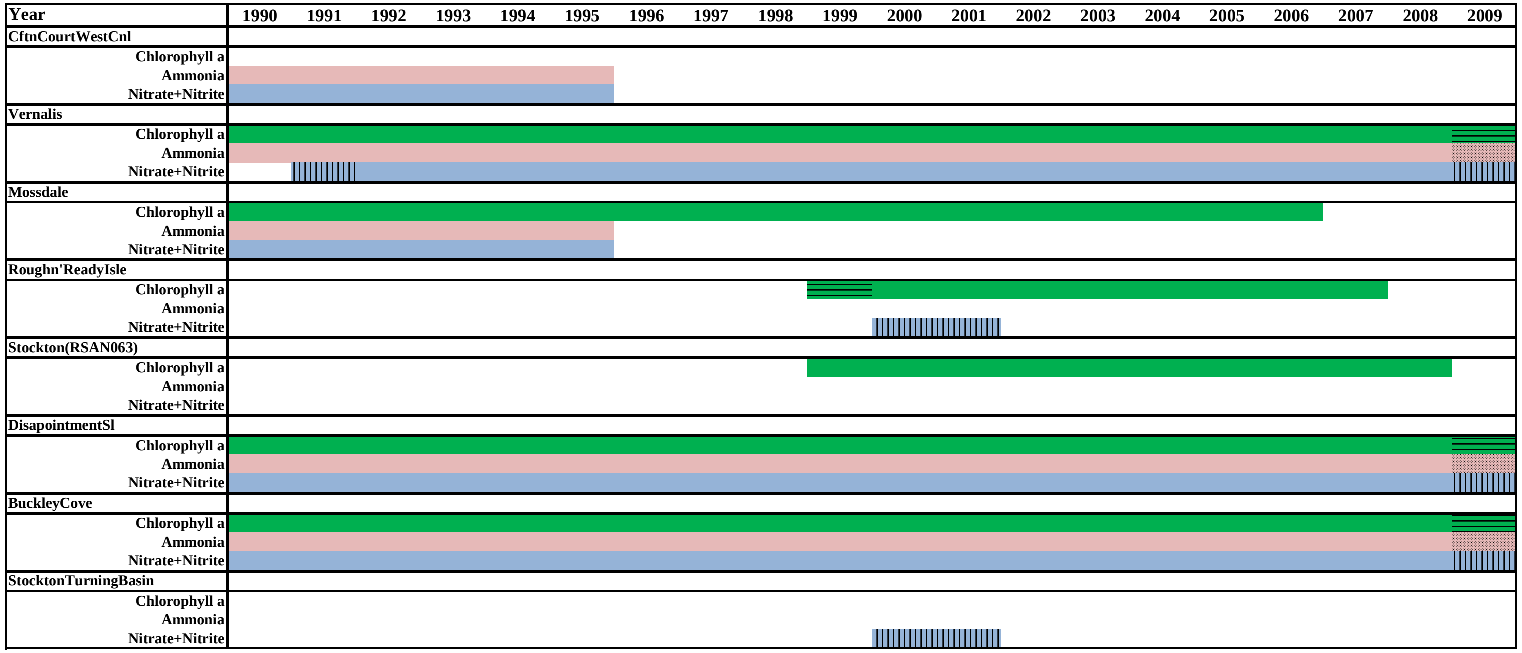


Figure 17-10 Availability of EMP/BDAT NH_3, NO_3+NO_2, and chlorophyll a measurements (Part 3). Hatching means partial-year data.

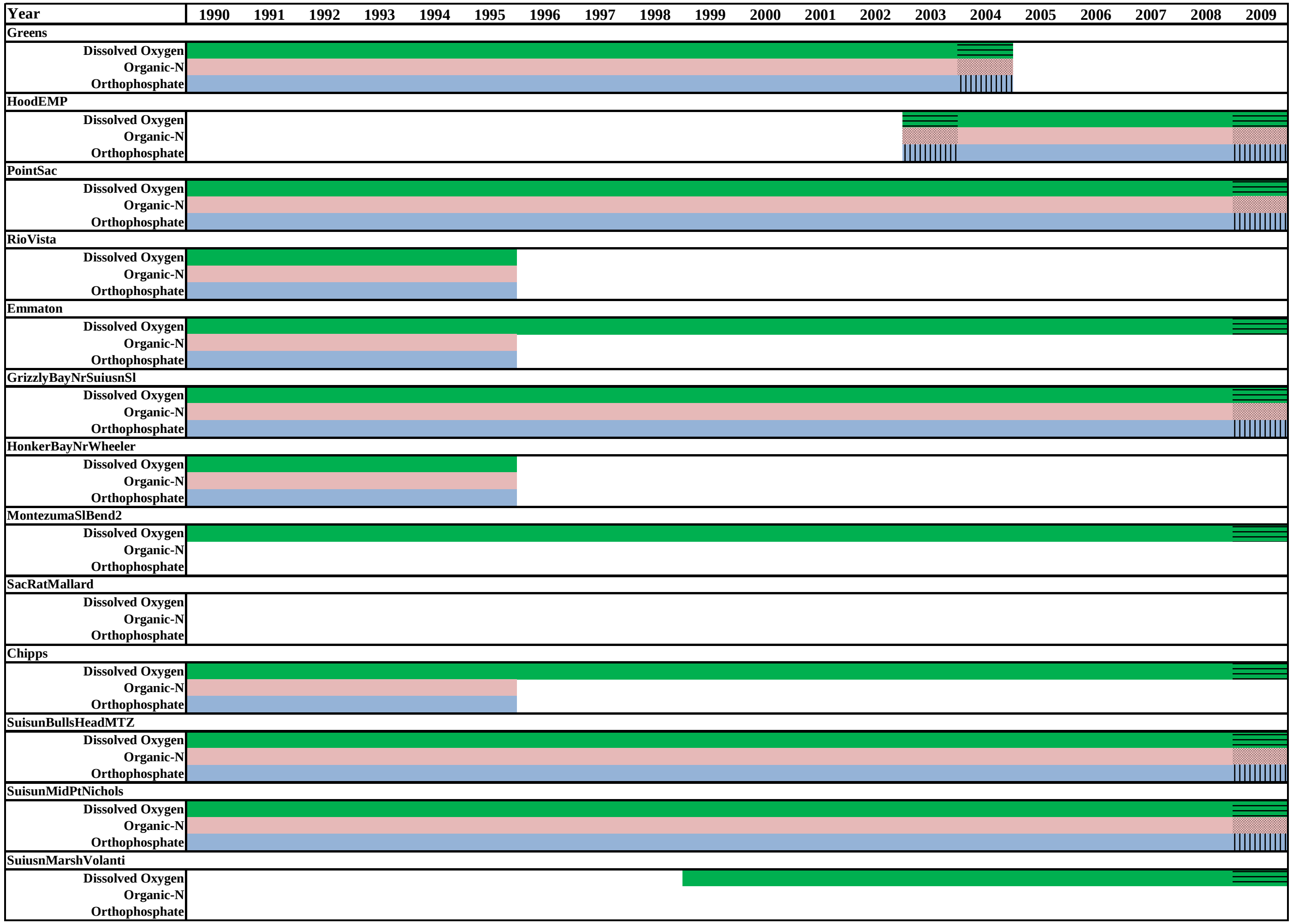


Figure 17-11 Availability of EMP/BDAT DO, Organic-N, and PO_4 measurements (Part 1). Hatching means partial-year data.

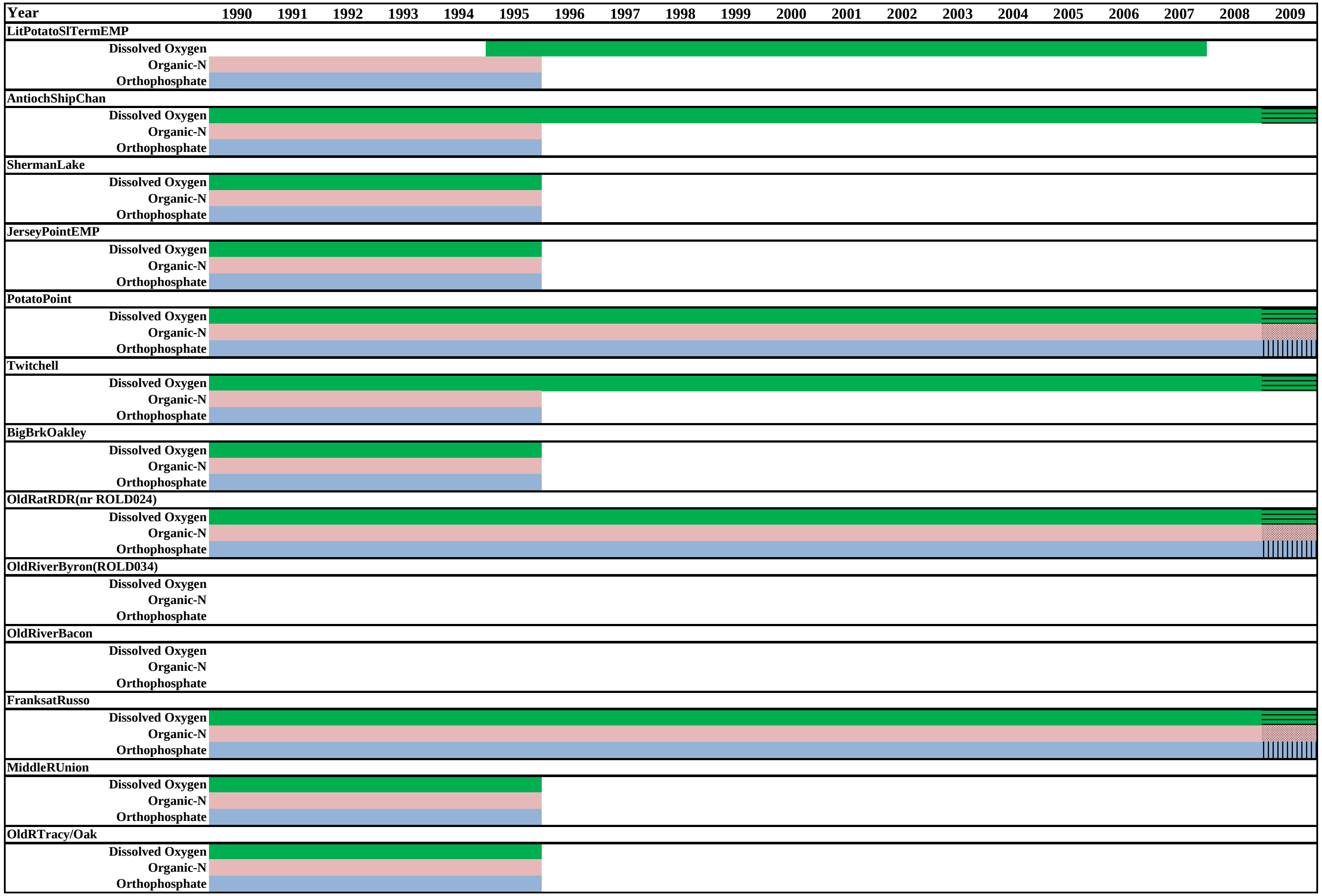


Figure 17-12 Availability of EMP/BDAT DO, Organic-N, and PO_4 measurements (Part 2). Hatching means partial-year data.

Figure 17-13 Availability of EMP/BDAT DO, Organic-N, and PO_4 measurements (Part 3). Hatching means partial-year data.

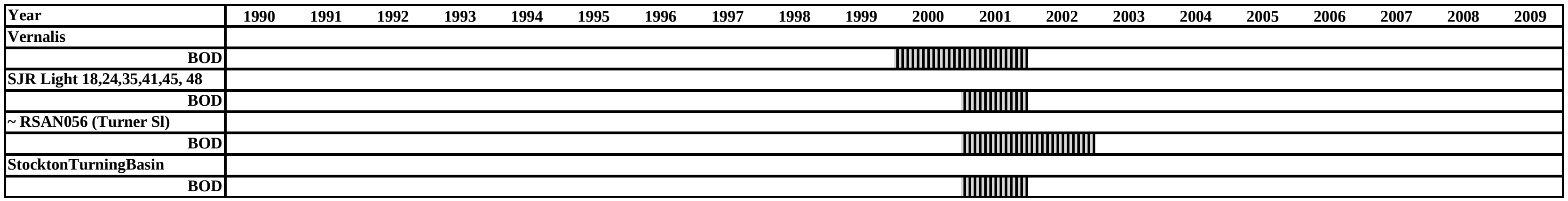


Figure 17-14 Availability of EMP/BDAT BOD measurements. Partial-year data only

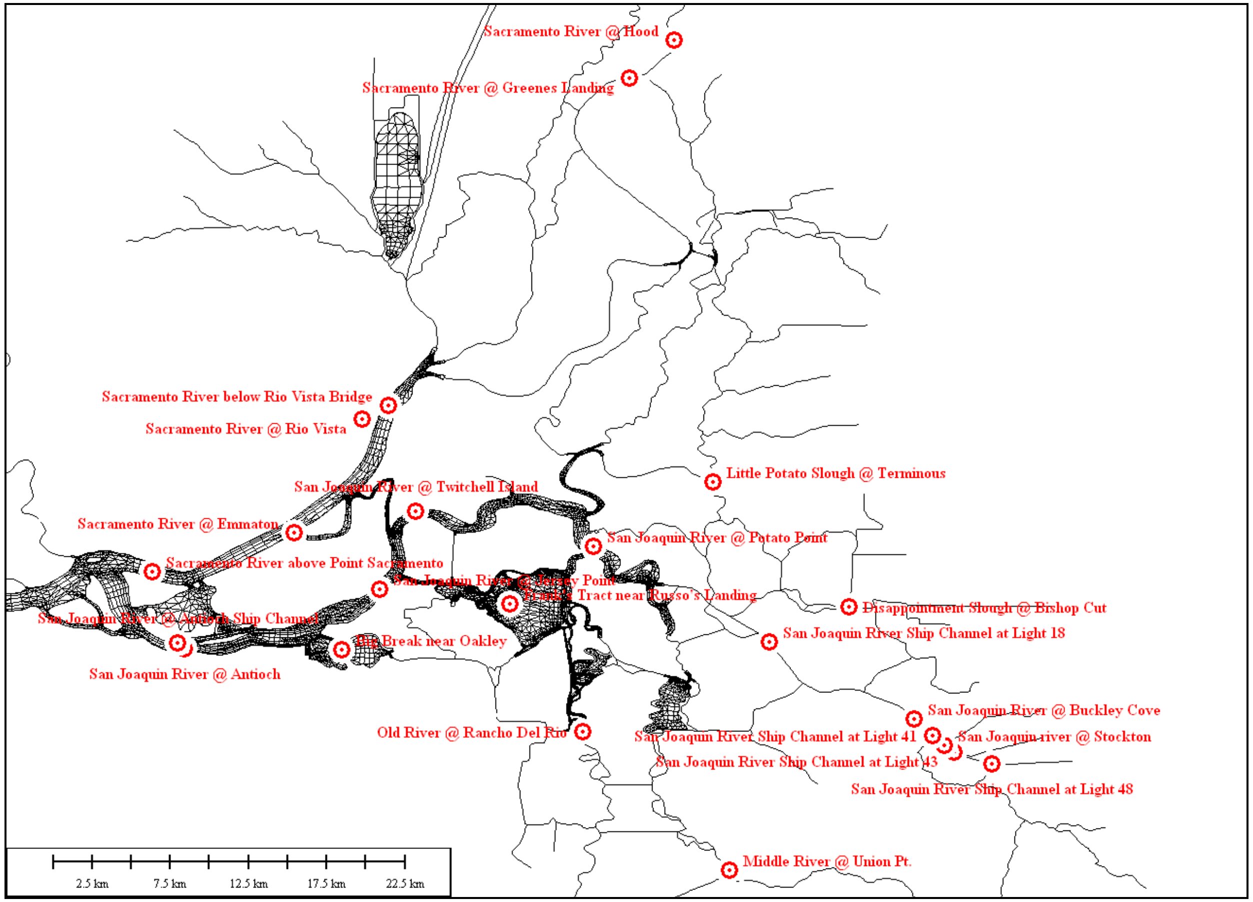


Figure 17-15 Location of BDAT grab-sample measurements for chl-a in the northern Delta.

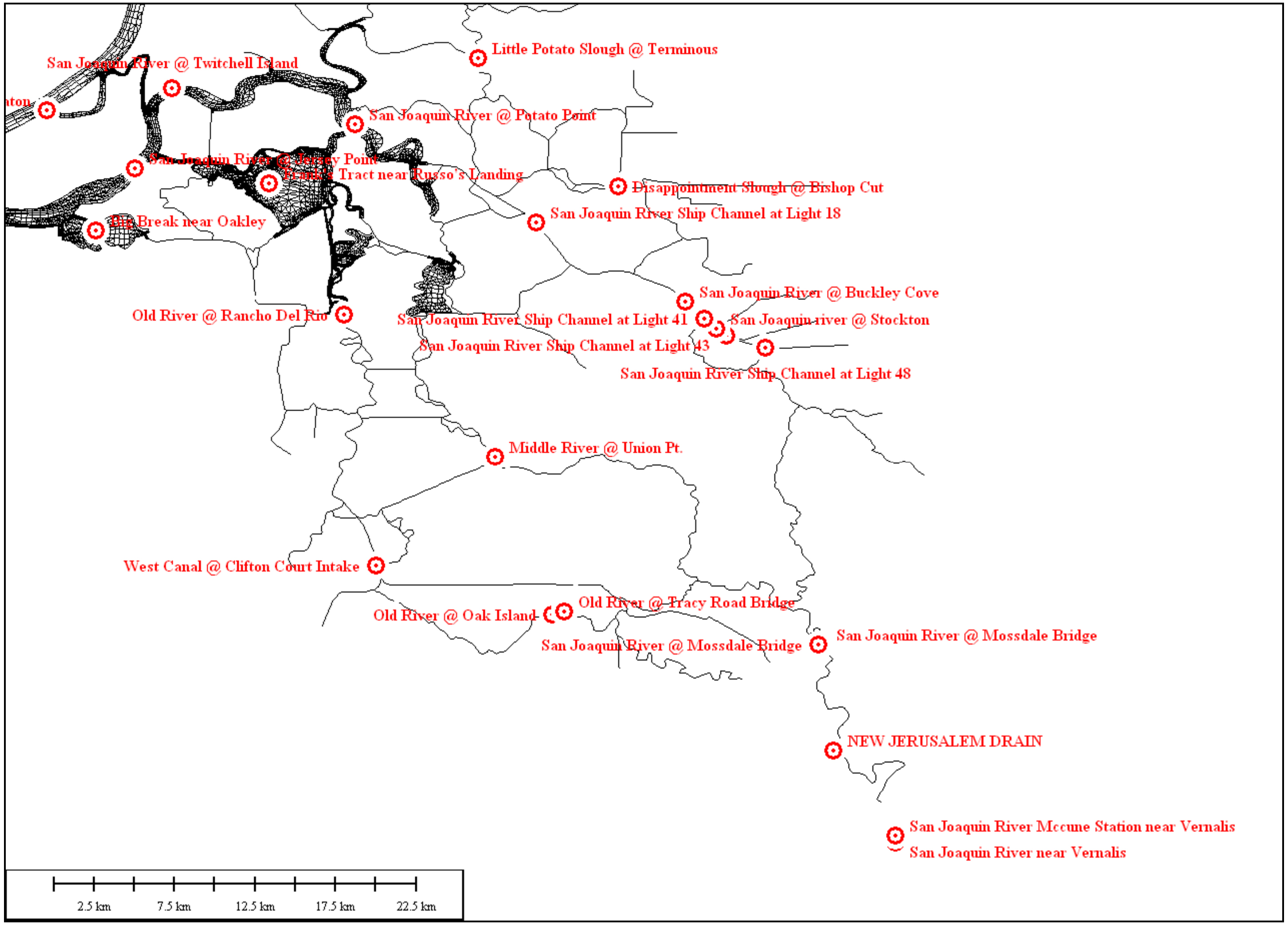


Figure 17-16 Location of BDAT-sourced grab-sample measurements for chl-a in the southern Delta.

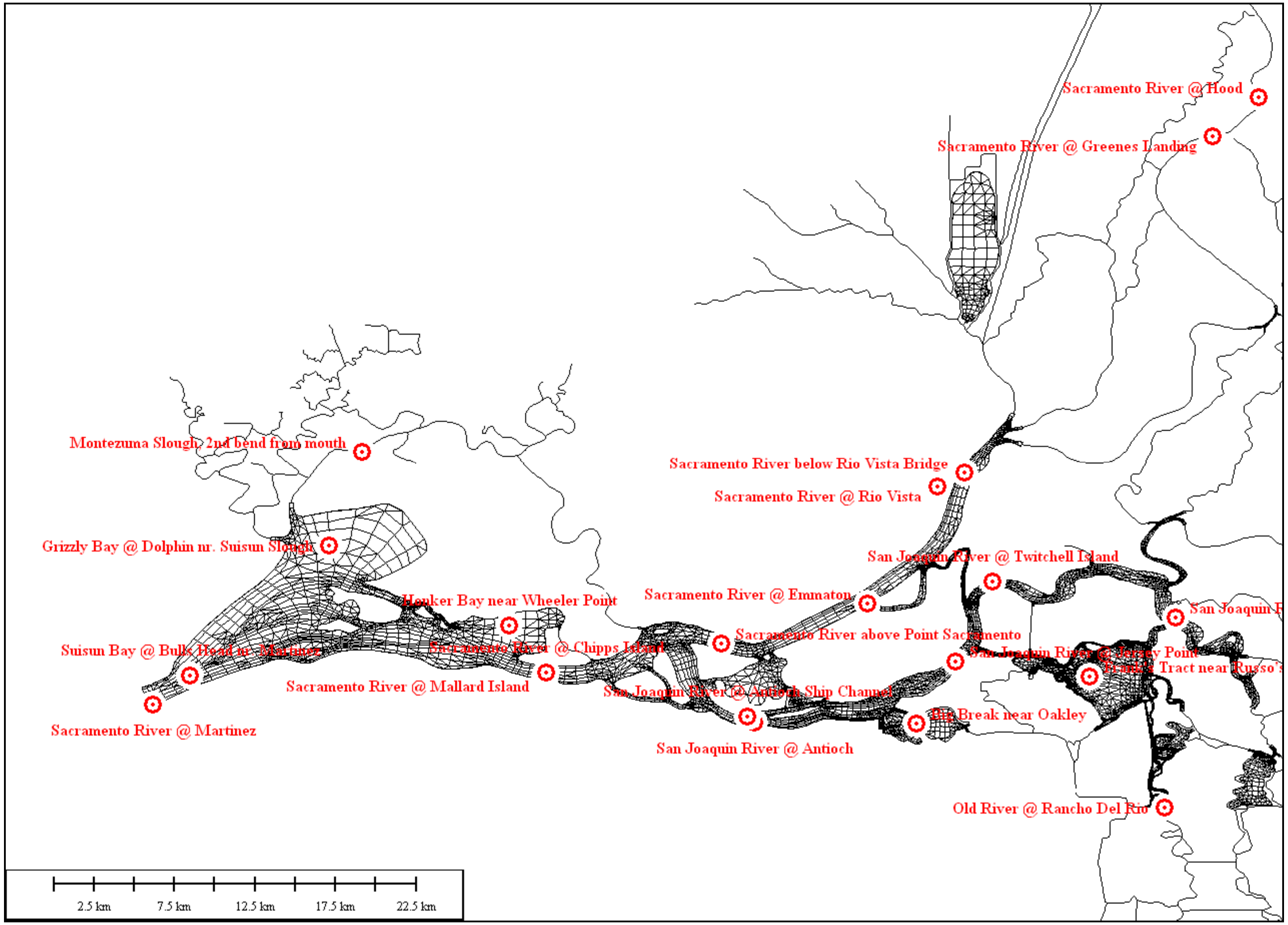


Figure 17-17 Location of BDAT grab-sample measurements for chl-a in the western Delta.

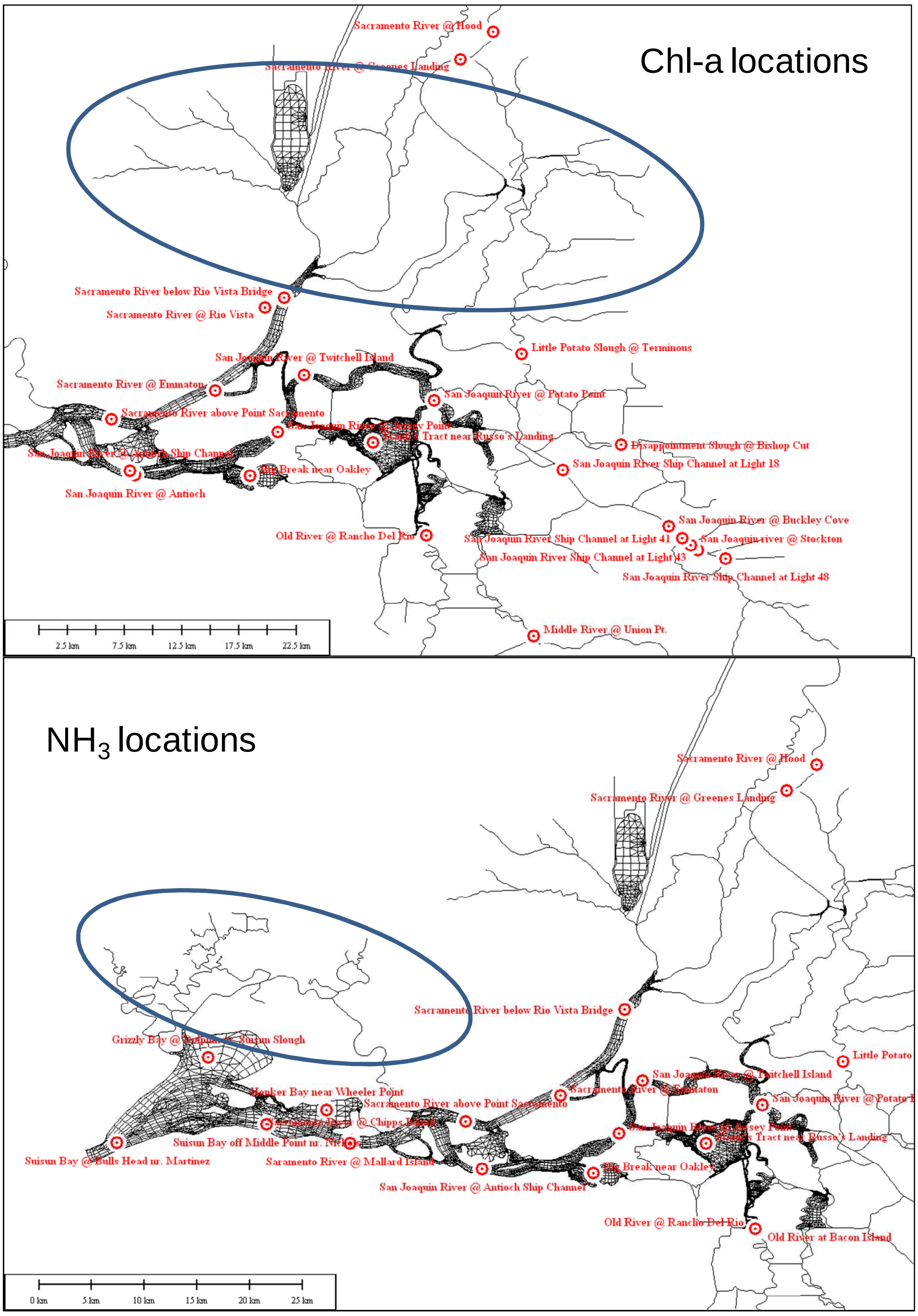


Figure 17-18 Nutrient levels in two large regions of the Delta are totally or partially unconstrained in calibration (i.e., no measurement data for some constituents).

Table 17-2 Nutrient data obtained from BDAT (#1)

Station Name	Name in Model	Station ID	Other Name	Latitude	Longitude	Sources
Antioch	Antioch	RSAN007		38.01777778	-121.801667	IEP
Between Navy and RR bridgesmg/L as N	TurnerCut	Turner Cut	CFTRN000, DSM2 Ch 172, L=727			BDAT
Big Break near Oakley	BigBrkOakley	D14A		38.01776	-121.7114	EMP
Carquinez Strait near Glencove Harbor	GlencoveHarbor	NZ002		38.06529	-122.2152	EMP
Carquinez Strait near Ozol Pier	OzolPier	NZ004		38.03576	-122.1616	EMP
City Of Stockton Treatment Plant	StocktonWWTP	FE(RWCF)	DSM2 Node 15			BDAT?
Clifton Court Intake	ClftCrtIntake	KA000000	DSM2 Res CLFCT	37.829781	-121.557353	WDL
Disappointment Slough @ Bishop Cut	DisapointmentSl	MD10	DSM2 Ch 317 L=7700	38.04381	-121.4188	EMP
Disappointment Slough @ Bishop Cut	DisapointmentSlA	MD10A	DSM2 Ch 317 L=7701	38.04226	-121.4199	EMP
Frank's Tract near Russo's Landing	FranksatRusso	D19	DSM2 Node 225	38.04376	-121.6148	EMP
From end of dock at Mossdale county park	MossdalePark	Mossdale				BDAT?
Georgiana Slough above Mokelumne River	GeorgianaSlatMoke	MD2	DSM2 RMKL005			EMP
Georgiana Slough at Walnut Grove Bridge	GeorgianaSlatWalnutGr	B9D81441309		38.2375	-121.516389	WDL
Grant Line/Fabian/Bell Canals nr Old R.	GrantLineNrOldR	B9D74931328		37.819444	-121.547222	WDL
Grant Ln Can @ Tracy Rd Bdg	GrantLineatTracy	B9D74921269		37.82	-121.448889	WDL
Grizzly Bay @ Dolphin nr. Suisun Slough	GrizzlyBayNrSuisunSl	D7	DSM2 Node 228	38.11714	-122.0397	EMP
Honker Bay near Wheeler Point	HonkerBayNrWheeler	D9	DSM2 Node 328	38.07244	-121.9392	EMP
Honker Cut at Atherton Road Bridge	HonkerCutatAtherton	B9D80361275		38.059444	-121.458333	WDL
Hood	HoodIEP	RSAC142		38.36805556	-121.519444	IEP
L. Potato Slough @ Terminous	LitPotatoSlTermWDL	B9D80691298		38.114722	-121.496389	WDL
Light 12	SJRLight12	Station ID from Kendall	SC-12	38.04267	-121.49883	SJRDO Study
Light 14	SJRLight14		SC-14	38.034	-121.48367	SJRDO Study
Light 28	SJRLight28		SC-28	37.99383	-121.4325	SJRDO Study
Light 34	SJRLight34		SC-34	37.994	-121.41367	SJRDO Study
Light 4	SJRLight4		SC-04	38.0555	-121.5295	SJRDO Study
Light 40	SJRLight40		SC-40	37.97817	-121.3825	SJRDO Study
Light 6	SJRLight6		SC-06	38.05383	-121.51517	SJRDO Study
Little Potato Slough @ Terminous	LitPotatoSlTermEMP	MD7A		38.11382	-121.498	EMP
Mallard Isl	MallardIsle	RSAC075		38.04361111	-121.918611	IEP
Mallard Slough	MallardSl	DO-62	? DSM2 SLML001	37.19187	-120.82379	SJRDO Study
Martinez	Martinez	RSAC054		38.02805556	-121.138056	IEP
Middle R. @ Borden Hwy.	MiddleRBordenHwy	B9D75351293	DSM2 RMID023	37.891111	-121.488889	WDL
Middle River @ Union Pt.	MiddleRUnion	P10A	DSM2 ec5500	37.89126	-121.4883	EMP
Middle River @ Victoria canal	MiddleRVictCanal	P10		37.8912	-121.4894	EMP
Middle River at Bacon Island Bridge	MiddleRBacon	B9D75741317		37.955833	-121.527778	WDL
Middle River North of Bacon Island Bridge	MiddleRBaconN	MD5				EMP
Mokelumne R. below Georgiana Sl	MokeBlwGeorgianna	B9D80771345		38.126944	-121.578333	WDL
Mokelumne River @ Franklin road bridge	MokeFranklin	P2		38.25542	-121.4403	EMP
Montezuma Slough, 2nd bend from mouth	MontezumaBend2	NZ032		38.16991	-122.0211	EMP
Mossdale	MossdaleIEP	RSAN087		37.78638889	-121.306111	IEP
NEW JERUSALEM DRAIN	NewJerusDrain	CDEC-NJD		37.7267	-121.2996	CDEC
Old R. nr. Byron (St 9) (NEAR HWY 4 BRIDGE)	OldRByron	B9D75351342	DSM2 ROLD034	37.891111	-121.569167	WDL
Old River @ Oak Island	OldROakIsle	P12A	DSM2 ROLD059	37.80284	-121.4569	EMP
Old River @ Rancho Del Rio	OldRatRDR	D28A	DSM2 ROLD024	37.97048	-121.573	EMP

Table 17-3 Nutrient data obtained from BDAT (#2)

Station Name	Name in Model	Station ID	Other Name	Latitude	Longitude	Sources
Old River @ Tracy Road Bridge	OldRTracyEMP	P12	DSM2 Ch 71, length	37.80472	-121.45	EMP
Old River at Bacon Island	OldRBacon	B9D75811344	DSM2 ROLD024	37.969444	-121.571111	WDL
Old River nr Tracy	OldRTracyWDL	B9D74731285	DSM2 ROLD059	37.788889	-121.475	WDL
Old River PP on Hwy 4	OldRHwy4	B9D75331345	DSM2 ROLD034	37.888333	-121.575278	WDL
Prisoner's Point/ Light 57	PrisonerPt	Prisoner Pt	SC-57	38.05967	-121.556	SJRDO Study
Rio Vista	RioVistalEP	RSAC101		38.145	-121.691667	IEP
Rock Slough at Contra Costa Canal Intake	RockSlatCCC	D27	DSM2 CHCCC006			EMP
Rough and Ready Island	RRIsland	Rough and Ready	DSM2 Ch 20, length			SJRDO Study
SACRAMENTO R A HOOD	HoodWDL	B9D82211312	RSAC142	38.368611	-121.520556	WDL
Sacramento River @ Chipps Island	Chipps	D10	DSM2 eiether Ch 437, 442 Length	38.04631	-121.9183	EMP
Sacramento River @ Emmaton	Emmaton	D22	Rsac092	38.08453	-121.7391	EMP
Sacramento River @ Greenes Landing	Greens	C3	PSAC139	38.34575	-121.5461	EMP
Sacramento River @ Hood	HoodEMP	C3A	RSAC142	38.36771	-121.5205	EMP
Sacramento River @ Mallard Island	MallardIsleEMP	D10A		38.044	-121.919	EMP
Sacramento River @ Martinez	MartinezEMP	D6A	RSAC054	38.028	-122.138	EMP
Sacramento River @ Rio Vista	RioVistaEMP	D24A	RSAC101	38.15	-121.7	EMP
Sacramento River @ Rio Vista Bridge	RioVistaWDL	B9D80961411		38.159722	-121.685	WDL
Sacramento River above Point Sacramento	PointSac	D4	DSM2 PO-649	38.06248	-121.8205	EMP
Sacramento River below Rio Vista Bridge	RioVistaBridge	D24		38.15778	-121.6847	EMP
Sacramento River below Walnut Grove	SacRWalnutGrove	MD1				EMP
San Joaquin R nr Vernalis	VernalisUSGS	11303500	RSAN112	37.67611111	-121.265278	USGS
San Joaquin R. @ Hwy 4	SJRatHwy4	B9D75571196	RSAN087	37.928333	-121.327222	WDL
San Joaquin R. @ Mossdale Bridge	MossdaleBrWDL	B9D74711184		37.786111	-121.305833	WDL
San Joaquin R. nr. Vernalis	VernalisWDL	B0702000	RSAN112	37.676111	-121.264167	WDL
San Joaquin River @ Antioch	Antioch	D12A	RSAN007	38.018	-121.802	EMP
San Joaquin River @ Antioch Ship Channel	AntiochShipChan	D12		38.02161	-121.8063	EMP
San Joaquin River @ Buckley Cove	BuckleyCove	P8	DSM2 P8-SJRBuck	37.97817	-121.3823	EMP
San Joaquin River @ Jersey Point	JerseyPointEMP	D15	RSAN018	38.05217	-121.6896	EMP
San Joaquin River @ Mossdale Bridge	MossdaleBrEMP	C7		37.78607	-121.3077	EMP
San Joaquin River @ Mossdale Bridge	MossdaleBrEMPA	C7A		37.786	-121.306	EMP
San Joaquin River @ Potato Point	PotatoPoint	D26	DSM2 Ch 44, 0	38.07664	-121.5669	EMP
San Joaquin river @ Stockton	Stockton	P8A	RSAN063	37.963	-121.365	EMP
San Joaquin River @ Twitchell Island	Twitchell	D16		38.0969	-121.6691	EMP
San Joaquin River at Bowman Road	SJRBowmanRd	R1				SJRDO Study
San Joaquin River at Brandt Bridge	SJRBrandtBr	C6	RSAN072	37.864926	-121.322723	EMP
San Joaquin River at Highway 4 Bridge	SJRHwy4Br	R2				SJRDO Study
San Joaquin River at Mossdale	MossdaleSJRDO	MY	RSAN087			SJRDO Study
San Joaquin River at Vernalis	VernalisSJRDO	VS	RSAN112			SJRDO Study
San Joaquin River Mccune Station near Vernalis	SJRMcCune	C10A		37.67929	-121.26511	EMP
San Joaquin River near Mokelumne River	SJRatMoke	MD11	DSM2 Ch 45, 0			EMP
SAN JOAQUIN RIVER NEAR VERNALIS	VernalisCDEC	CDEC-VNS	RSAN112	37.667	-121.267	CDEC
San Joaquin River near Vernalis	VernalisEMP	C10	RSAN112	37.67575	-121.265	EMP

Table 17-4 Nutrient data from BDAT (#3)

Station Name	Name in Model	Station ID	Other Name	Latitude	Longitude	Sources
San Joaquin River Ship Channel at Light 18	SJRLight18	R8	SC-18	38.02183	-121.46567	SJRDO Study
San Joaquin River Ship Channel at Light 19	SJRLight19	Lt 19	SC-19	38.01067	-121.45667	SJRDO Study
San Joaquin River Ship Channel at Light 24	SJRLight24	R7				SJRDO Study
San Joaquin River Ship Channel at Light 36	SJRLight36	R6				SJRDO Study
San Joaquin River Ship Channel at Light 38	SJRLight38	SJR Ship Channel @ Lt 38				SJRDO Study
San Joaquin River Ship Channel at Light 41	SJRLight41	R1	SC-41	37.96867	-121.3715	SJRDO Study
San Joaquin River Ship Channel at Light 43	SJRLight43	SJR Ship Channel @ Lt 43	SC-43	37.95867	-121.35933	SJRDO Study
San Joaquin River Ship Channel at Light 45	SJRLight45	R4				SJRDO Study
San Joaquin River Ship Channel at Light 48	SJRLight48	SJR Ship Channel @ Lt 48	SC-48	37.95217	-121.33783	SJRDO Study
Saramento River @ Mallard Island	SacRatMallard	E0B80261551	RSAC075	38.043611	-121.918611	WDL
Sherman Lake near Antioch	ShermanLake	D11		38.04229	-121.7995	EMP
SJR at Mossdale	MossdaleSJRDO2	DO-04	RSAN087	37.7871	-121.30757	SJRDO Study
South Fork Mokelumne below Sycamore Slough	SForkMokeblwSycmrSl	MD7		38.12513	-121.497	EMP
Stockton	StocktonIEP	RSAN063		37.96277778	-121.365	IEP
Stockton Turning Basin	StocktonTurnBasin	TB	SC-STB, STKN-TB	37.95233	-121.31733	SJRDO Study
Suisun Bay @ Bulls Head nr. Martinez	SuisunBullsHeadMTZ	D6	near DSM2 RSAC054	38.04436	-122.1177	EMP
Suisun Bay near Preston Point	SuisunPrestonPt	D2		38.06544	-122.0545	EMP
Suisun Bay off Middle Point nr. Nichols	SuisunMidPtNichols	D8	DSM2 SLML001	38.05992	-121.99	EMP
Suisun Slough @ Volanti Slough	SuisunatVolanti	NZS42	DSM2 SLSUS012	38.18045	-122.0476	EMP
Suisun Slough 300' south of Volanti Slough	SuisunSofVolanti	S42		38.18047	-122.0469	EMP
Sycamore Slough near Mouth	SycamoreSlMouth	MD6		38.1415	-121.4687	EMP
Turning Basin Deep Water Ship Channel at Port of Stockton	PortofStockton	Turning Basin	SC-STB, STKN-TB	OK - MG can locate		SJRDO Study
West Canal @ Clifton Court Intake	CliftnCourtWestCnl	C9	DSM2 Node 72	37.83028	-121.5549	EMP
White Slough above Honker Cut	WhiteSlHonkerCut	MD9				EMP

Table 17-5 Sacramento Regional WWTP receiving water data at the Freeport location from 2004 – 2008. ***Italic fon*****t indicates the measurement was at the instrument detection limit.**

Freeport	DOC mg/L	DO mg/L	EC umhos/cm	pH	Temp (° C)	TOC mg/L	Turbidity NTU	Ammonia mg/L	Nitrate mg/L	Nitrite mg/L	Orthophosphate-dissolved mg/L	Phosphorus as P mg/L	TKNmg/L
08/10 - 11/04	1.8	10	150	7.7	21.6	1.9	9.4	*0.10*	0.10	0.100	0.130	0.20	0.51
10/5/2004	1.8	10	150	7.7	21.6	1.9	9.4	*0.10*	0.10	0.100	0.130	0.20	0.51
10/19-20/04	1.6	10	130	7.4	16.1	1.7	6.4	*0.10*	0.14	0.100	0.150	0.10	0.19
12/07-08/04	2.5	14	210	7.9	9.10	2.6	9.1	*0.10*	0.17	0.100	*0.100*	0.13	0.40
1/28-29/05	2.3	11	250	7.9	10.2	2.4	24	*0.10*	0.32	0.100	*0.100*	0.13	0.36
02/15-16/05	2	14	200	7.8	11.3	2	11	*0.10*	0.27	0.100	0.110	0.085	0.29
04/12-13/05	1.9	12	150	7.7	14.8	1.8	19	*0.10*	0.15	0.100	*0.100*	0.050	0.50
06/07-08/05	1.3	8.5	110	7.7	17.4	1.3	11	*0.10*	0.10	0.100	0.050	0.050	0.25
8/2/2005	1.7	12	150	8.1	22.1	1.7	13	*0.1*	0.11	*0.100*	*0.050*	0.17	0.062
10/4/2005	1.4	13	130	7.8	16	1.4	6.2	*0.1*	0.1	*0.100*	*0.050*	0.29	*0.05*
12/1/2005		11	190	7.7	10.5		12	0.1	0.16	*0.100*	0.060	0.37	0.078
2/7/2006	2.2	12	100	7.2	9.7	3.3	55	*0.1*	0.12	*0.100*	0.050	0.16	0.059
2/27/2006	3.3	15	130	7.7	10.4		19	*0.1*	0.27	*0.100*	0.055	0.1	*0.05*
3/7/2006		16	95	7.4	9.6		39						
4/4/2006	3	14	95	7.6	10.2	2.4	38	*0.1*	*0.1*	*0.100*	0.050	0.31	0.075
6/13/2006	2.8	10	180	7.7	18	1.2	18	*0.1*	*0.1*	*0.100*	0.050	0.25	*0.05*
8/3/2006	11	11	140	7.8	21	*2.1*	16	*0.1*	*0.1*	*0.100*	*0.050*	*0.2*	*0.05*
10/11/2006	1.3	9.1	140	7.8	16.9	3.6	6.2	*0.1*	*0.15*	*0.100*	*0.050*	*0.27*	*0.05*
11/3/2006	1.5	11	140	7.7	14.6	*2.1*	5.9	*0.1*	0.17	0.100	*0.050*	*0.36*	*0.05*
12/9/2006	1.1	12	170	7.6	10	*1.8*	10	*0.1*	*0.14*	*0.100*	*0.050*	*0.32*	*0.054*
2/8/2007	2.8	13	190	7.6	10.5	5.2	14	0.14	0.13	*0.100*	*0.050*	0.5	0.054
4/3/2007	4.5	11	130	7.9	15.9	3.9	6.8	*0.1*	*0.1*	*0.100*	*0.050*	0.2	*0.05*
6/5/2007	5.6	9.2	210	7.1	21.5	6.8	6.2	*0.1*	*0.1*	*0.100*	*0.050*	0.27	*0.05*
08/07/2007 - 8/8/2007	2.0	9.1	180	7.8	19.8	2.0	7.4	0.028	0.039	*0.0029*	0.0140	0.05	0.18
10/09/2007 - 10/10/2007	1.2	10	170	7.9	16.5	1.4	3.2	0.026	0.082	0.0020	0.0240	0.034	0.57
12/04/2007 - 12/5/2007		10	190	7.8	10.4		11	0.042	0.14	0.0042	0.0680	0.042	0.48
01/04/2008 - 01/05/2008	2.7	14	200	7.8	7.67	2.7	20	0.12	0.25	0.0056	0.0480	0.065	0.89
02/05/2008 - 02/06/2008	5.2	13	150	7.6	7.2	3.6	250	0.017	0.31	0.0063	0.0390	0.24	0.89
04/01/2008 - 04/03/2008	1.9	10	200	8	14.4	2.1	7.2	*0.1*	0.13	0.0034	0.0330	*0.05*	0.81
06/11/2008 - 06/11/2008	3.6	8.9	130	7.7	19.8	4.9	12	*0.062*	0.023	*0.0031*	0.0260	0.044	0.51
Average	2.7	11.5	158.7	7.7	14.5	2.6	22.5	0.1	0.1	0.0039	0.1	0.2	0.3
Max	11.0	16.0	210.0	8.1	22.1	6.8	250.0	0.1	0.3	0.0063	0.1	0.5	0.9
Min	1.1	8.5	95.0	7.1	7.2	1.2	3.2	0.0	0.0	0.0020	0.0	0.0	0.1

Table 17-6 Sacramento Regional WWTP receiving water data at the RM 44 (River Mile 44) location from 2004 – 2008. *Italic fon*t indicates the measurement was at the instrument detection limit.

RM 44	DOC mg/L	DO mg/L	EC umhos/ cm	pH	Temp (° C)	TOC mg/L	Turbidity NTU	Ammonia mg/L	Nitrate mg/L	Nitrite mg/L	Orthophosphate-dissolved mg/L	Phosphorus as P mg/L	TKN mg/L
8/10-11/04	1.9	11	160	7.7	21.8	1.7	9.7	0.14	0.10	0.10	0.10	0.078	0.40
10/5-6/04	1.4	9.6	150	7.8	19.4	1.6	6.5	0.24	0.11	0.10	0.10	0.11	0.70
12/7-8/04	2.6	14	210	7.6	9.10	3	7.3	0.32	0.17	0.10	0.10	0.16	0.76
2/15-16/05	2.2	14	220	7.5	11.4	2.3	12	0.38	0.25	0.10	0.10	0.11	0.73
4/12-13/05		12	160	7.7	14.7		20	0.12	0.16	0.10	0.10	0.058	0.79
6/7-8/05	1.4	9.9	120	7.6	17.5	1.3	14	0.14	0.10	0.10	0.050	0.10	0.47
8/2/2005	1.5	9.8	160	8	22.3	1.6	9.2	0.21	*0.1*	*0.1*	0.074	0.48	0.11
10/4/2005	1.6	13	140	7.6	16.3	1.8	7	0.32	*0.1*	*0.1*	0.06	0.67	0.079
12/1/2005		10	190	7.4	10.6		11	0.42	0.15	*0.1*	0.069	0.85	0.088
2/7/2006	2.2	12	97	6.5	9.8	3.1	58	*0.1*	0.15	*0.1*	*0.05*	0.28	0.072
4/4/2006	3	14	98	7.5	10.2	2.2	43	0.12	0.11	*0.1*	*0.05*	0.35	0.083
6/13/2006	2.3	11	190	7.4	18	0.91	13	0.12	0.14	*0.1*	0.051	0.5	0.064
8/3/2006	*1*	11	150	7.5	20.9	*2.5*	12	*0.1*	*0.15*	*0.1*	*0.05*	*0.45*	*0.085*
10/11/2006	1.9	9.1	140	7.8	17.1	*1.8*	7.1	*0.31*	*0.47*	*0.1*	*0.077*	0.76	*0.11*
12/9/2006	2.4	12	180	7.7	10.2	*1.5*	11	*0.39*	*0.14*	*0.1*	*0.052*	0.71	*0.082*
2/8/2007	2.5	13	200	7.6	10.7	5.5	16	0.41	0.13	*0.1*	0.064	0.76	0.07
4/3/2007	4.3	11	140	7.7	16	4.3	8.7	0.34	*0.1*	*0.1*	0.05	0.81	0.054
6/5/2007	6.3	8.3	220	7	21.6	6.6	6.4	*0.1*	*0.1*	*0.1*	0.058	0.7	*0.05*
08/07/2007 - 8/8/2007	2.0	9	190	7.7	20	1.5	6.8	0.11	0.026	*0.0082*	0.027	0.036	0.45
10/09/2007 - 10/10/2007	1.7	10	180	7.6	16.7	1.9	4.8	0.37	0.082	0.0027	0.074	0.096	0.84
12/04/2007 - 12/5/2007		10	200	7.5	10.3		6.3	0.29	0.15	0.0044	0.1	2.5	0.73
02/05/2008 - 02/06/2008	5.5	12	150	6.8	7.1	3.6	260	0.088	0.29	0.0061	0.046	0.21	0.99
04/01/2008 - 04/03/2008	2	10	190	7.9	14.3	2	5.7	0.077	0.12	0.0035	0.04	0.046	0.88
06/11/2008 - 06/11/2008	3.1	8.6	150	7.3	19.5	2.8	12	0.34	0.036	*0.0039*	0.058	0.085	0.83
Average	2.5	11.0	166.0	7.5	15.2	2.5	23.6	0.23	0.14	0.0048	0.07	0.45	0.40
Max	6.3	14.0	220.0	8.0	22.3	6.6	260.0	0.42	0.47	0.0042	0.10	2.50	0.99
Min	1.0	8.3	97.0	6.5	7.1	0.9	4.8	0.08	0.03	0.0045	0.03	0.04	0.05

17.3 CBOD and BOD

Biochemical Oxygen Demand, or BOD, is a test used to measure the mass of oxygen consumed for unit volume of water, and is considered a measure of the concentration of biodegradable organic material present in solution (Brake 1998). It is a widely used test important in nutrient studies as dissolved oxygen is consumed when organic matter is oxidized by microbes. The measurement is further distinguished by the number of days the test is allowed to run, so the BOD_5 test runs for 5 days. BOD_5 is typically assumed to represent about 60 – 80% of the ultimate BOD, or BOD_u, which is the measurement taken after 20 days. Waste water treatment plants frequently measure BOD in the effluent as receiving waters can only assimilate limited quantities of organic matter before adverse effects occur.

The BOD measurement can be split into two stages – Carbonaceous BOD, or CBOD, and Nitrogenous BOD, or NBOD. CBOD measures the oxygen consumption due oxidation of carbon and NBOD measures the oxygen consumed due to the oxidation of nitrogenous compounds. Because nitrifying bacteria can take 8 – 10 days before sufficient numbers are available to oxidize the N-compounds, BOD_5 is an approximate measure of CBOD after correction factor for the length of the test. Unless nitrification is inhibited in the BOD test, longer BOD tests such as BOD_{20} will include the NBOD.

In reality, all organic matter is not equal in terms of a BOD, CBOD or NBOD measurements. Some organic material is labile, or easily utilized by microbes, and some is refractory or recalcitrant, i.e., practically unavailable as an energy source over the short term. For example, sewage effluent organic matter is considered labile, while paper mill effluent is refractory or recalcitrant in nature (Chapra, 2008).

Some WWTPs measure both BOD_5 and CBOD, such as City of Stockton WWTP and Lodi WWTP. Regression relationships between BOD_5 and CBOD for these measurements sets give similar regression relationships. Stockton WWTP had a fairly extensive set of measurements to compare which gave the following regression relationship which was used to convert all BOD_5 to CBOD:

$$CBOD = (0.48)* BOD_5 + 0.8.$$

17.4 Fluorescence Data

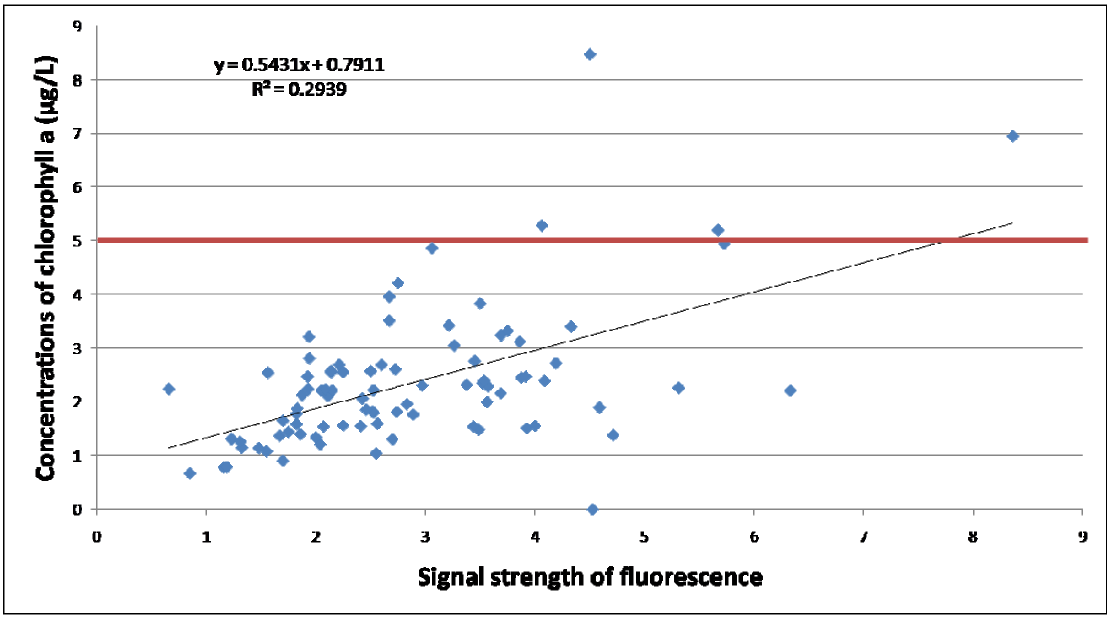


Figure 17-19 Linear regression between concentration of chlorophyll a and signal strength of fluorescence at Hood. Red line indicates 5 µg/L of Chlorophyll a.

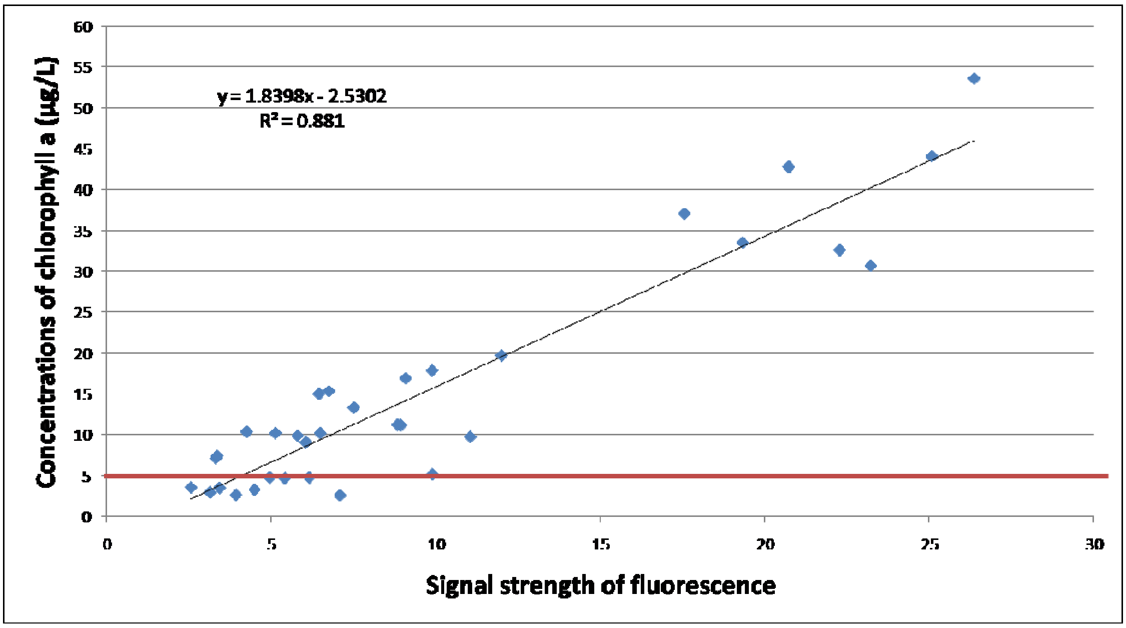


Figure 17-20 Linear regression between concentration of chlorophyll a and signal strength of fluorescence at Mossdale. Red line indicates 5 µg/L of Chlorophyll a.

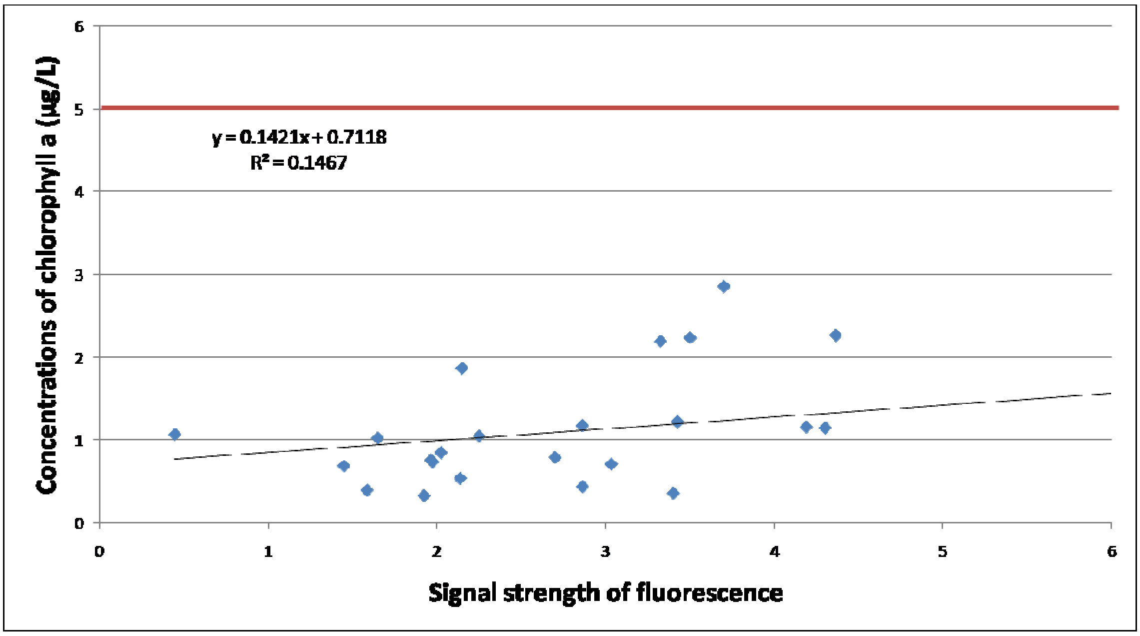


Figure 17-21 Linear regression between concentration of chlorophyll a and signal strength of fluorescence at Martinez. Red line indicates 5 µg/L of Chlorophyll a.

17.5 Singular Spectrum Analysis

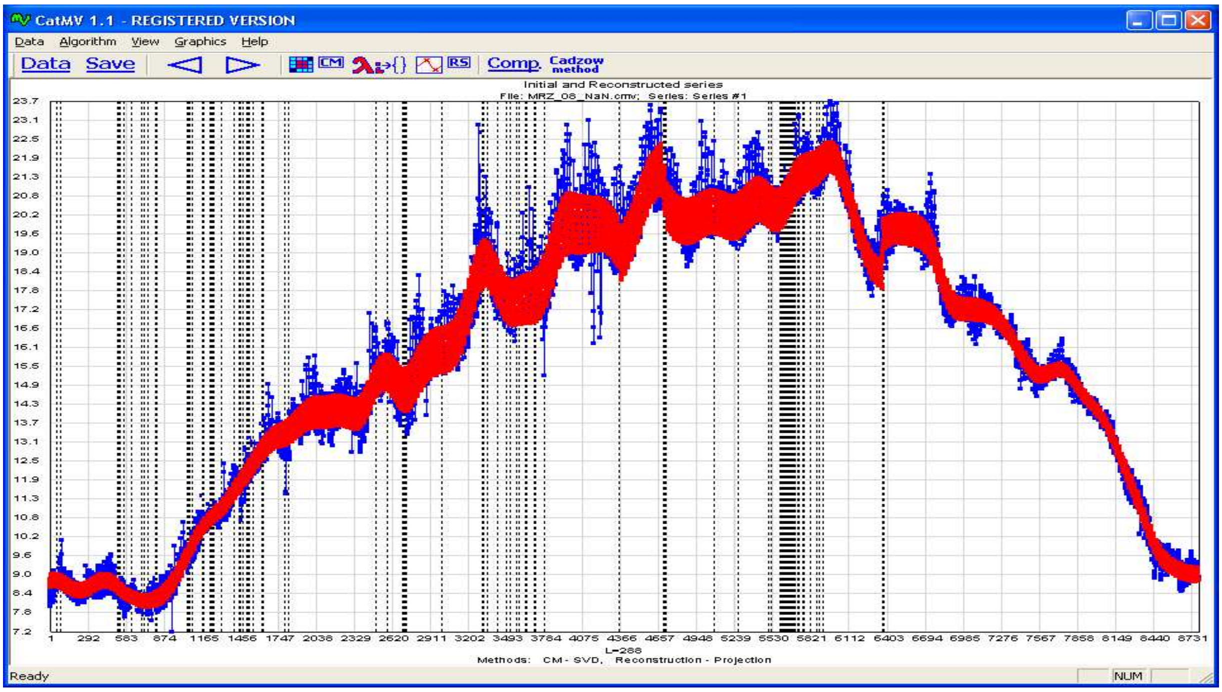
Singular Spectrum Analysis (SSA) is essentially a variation on Principle Components Analysis. This is a relatively new analytical method used in various fields to analyze time series data (*e.g.*, stream flow, global temperature). Schoelhammer (2001) developed and used SSA methodology to fill data gaps in suspended sediment concentration data – up to 50% of the data in the time series was missing or invalid, and SSA was used to fill these data gaps. When used for filling data gaps, the SSA methodology is akin to forecasting methodology for time series.

For this project, a software package CAT-MV (for the "Caterpillar-SSA" method) was purchased to use in filling data gaps for continuous (15-minute or hourly interval) data. CAT-MV uses the SSA method to approximate time series data and fill in missing data with approximations. As illustrated in Figure 17-22 to Figure 17-24, below, the following methodology was used on data that had been pre-screened to remove invalid data:

- A time series of data of a given length (such as a year or several months) was selected and imported into the CAT-MV software
- A window length, related to the length of the largest data gap was selected and the SSA methodology was used in the software to approximate the time series
- The software develops a lagged set of sub-vectors (the lag is related to the "window length") to form a trajectory matrix $\boldsymbol{X}$
- An orthogonal basis of eigenvectors for the matrix $\boldsymbol{X}{*}\boldsymbol{X}^t$ is calculated to approximate the time series as a set of additive components to estimate trend and periodicity
- A subset of the entire solution set is selected by the user to approximate the data, the fit is examined, and the resulting approximated dataset is exported
- Gaps in the original dataset are then filled using the SSA approximations, but the original data is retained.

Figure 17-22 shows that for a time series of hourly water temperature data at Martinez with short gaps (black lines), using a larger set of approximating eigenvectors (24 instead of 4) significantly improved the fit. The CAT-MV (red lines) approximations to hourly water temperature data (blue lines) at Martinez both used a window length of 288 hours. Black vertical lines indicate missing data points. The upper plot used only 4 out of the available eigenvectors, while the lower plot used 24 eigenvectors. Figure 17-23 shows the residuals from one year (upper) and two-year approximations to this data. Residuals are larger in summer months, but are generally within +/-

1 °C. Longer data gaps (Figure 17-24) were generally approximated better using a window length shorter than the data gap.



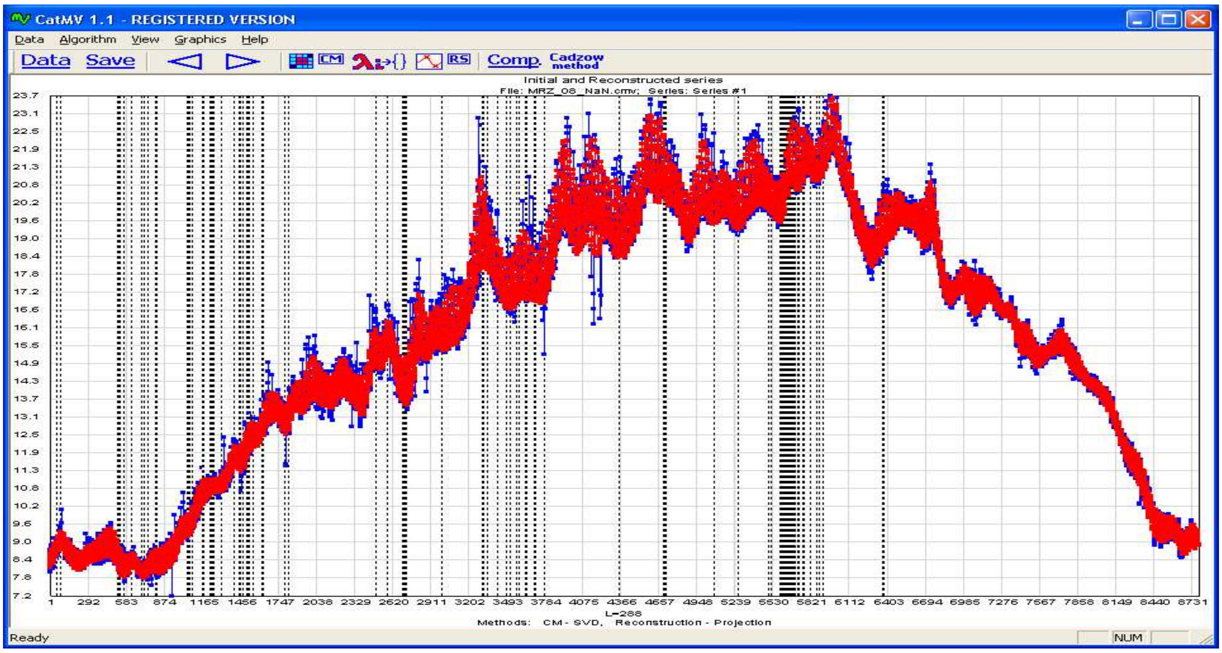


Figure 17-22 CAT-MV (red lines) approximations to hourly water temperature data (blue lines) at Martinez. Black vertical lines indicate missing data points. Upper plot used 4 eigenvectors, the lower plot used 24.

Residuals and Histogram WL=288, EV = 24, One Year MTZ

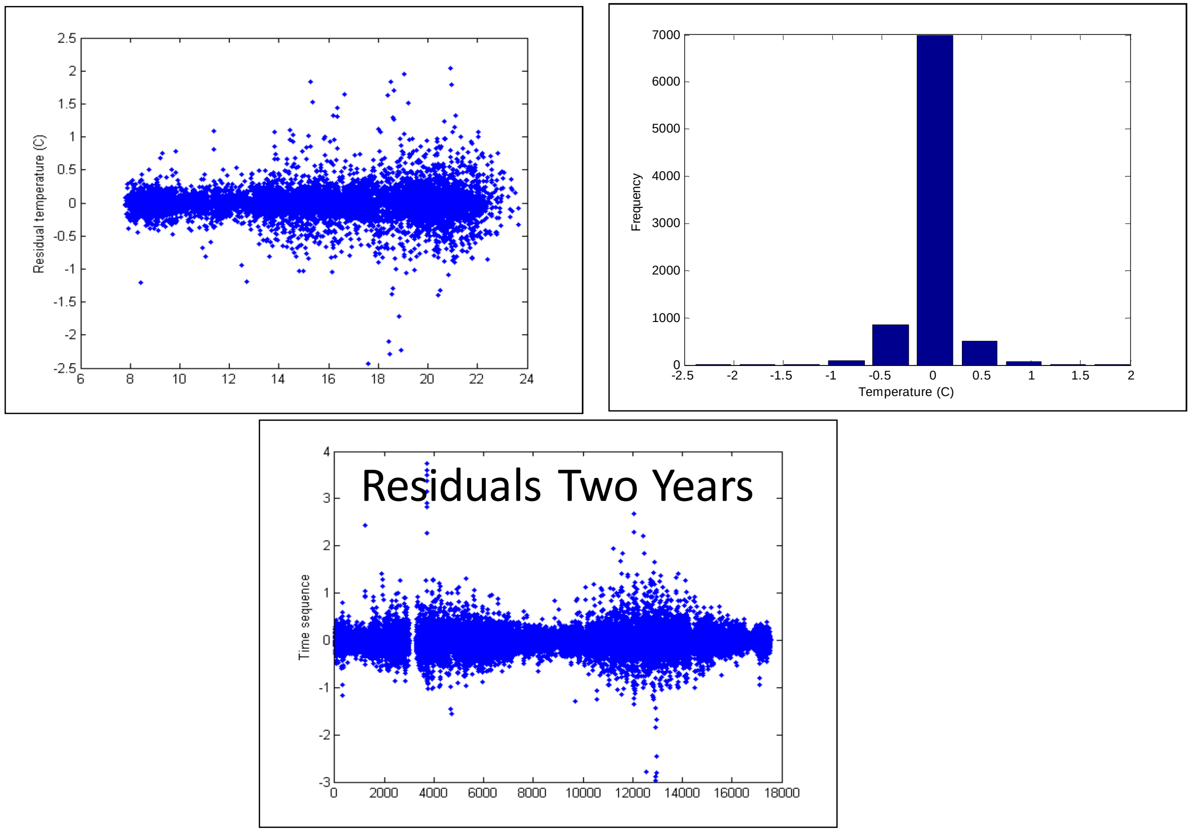


Figure 17-23 Upper: Residual plot and histogram of a Cat-MV model fit to one-year of hourly water temperature at Martinez, window length was 288, 24 eigenvectors. Lower: Residuals applied to a two-year data set: the fit during summer months poor in comparison to winter.

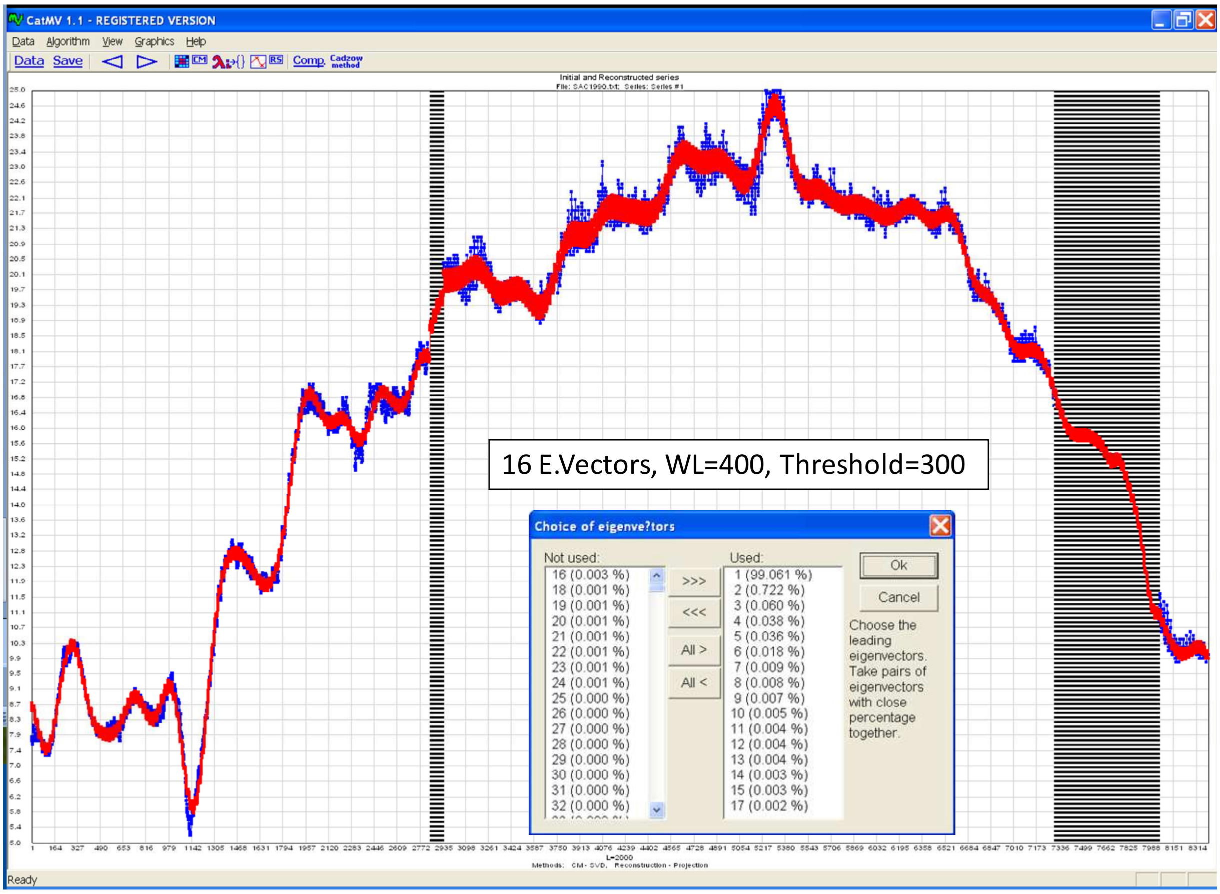


Figure 17-24 Large data gaps (dark bands) used a window length shorter than the largest data gap to get better results. Cat-MV fit (red) to the data series (blue line) and the missing data.

17.6 Model Boundary Conditions

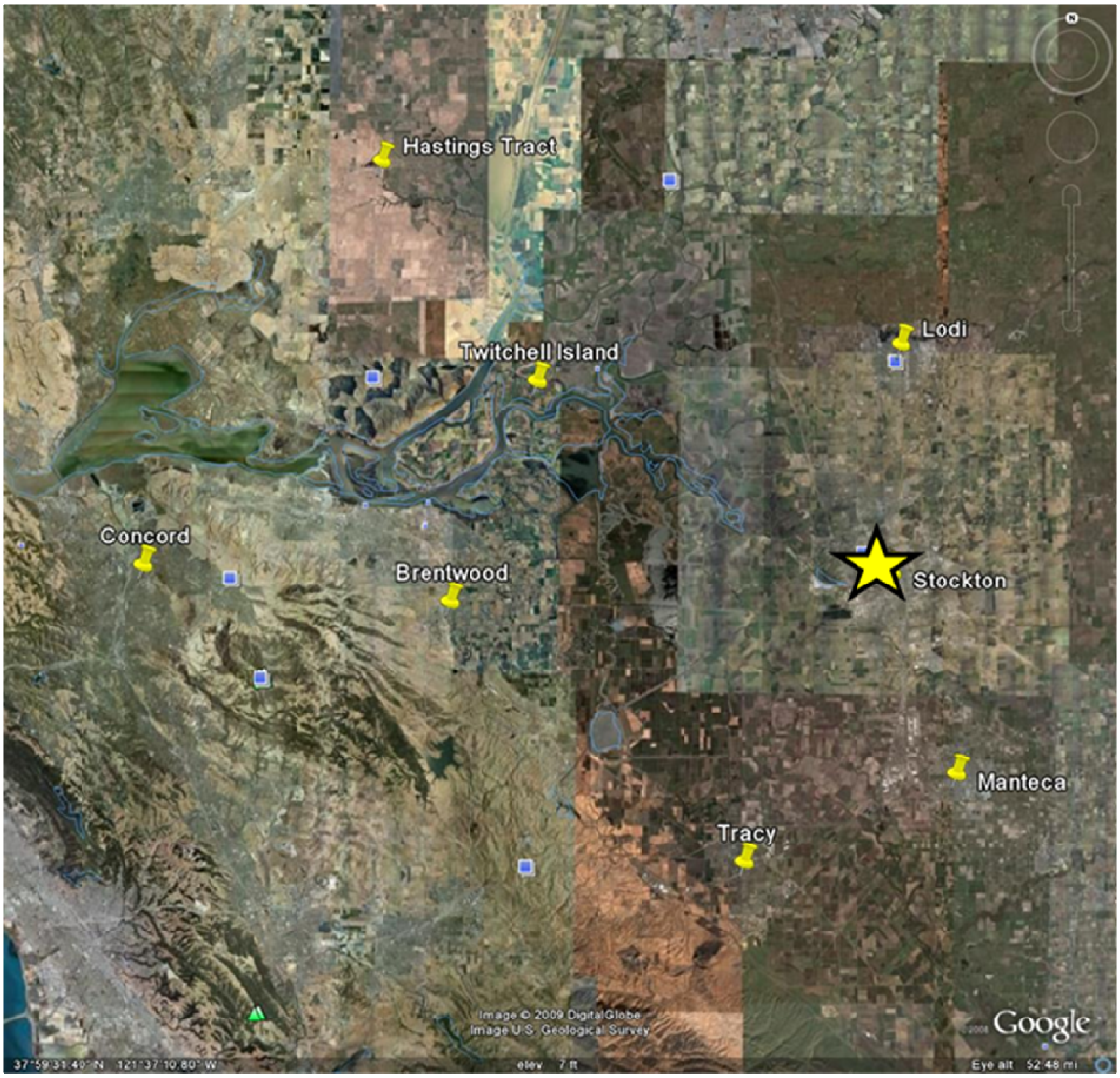


Figure 17-25 Meteorological measurements from NOAA at the Stockton airport (yellow star), and CIMIS measurements, indicated by yellow Google Earth push-pins.

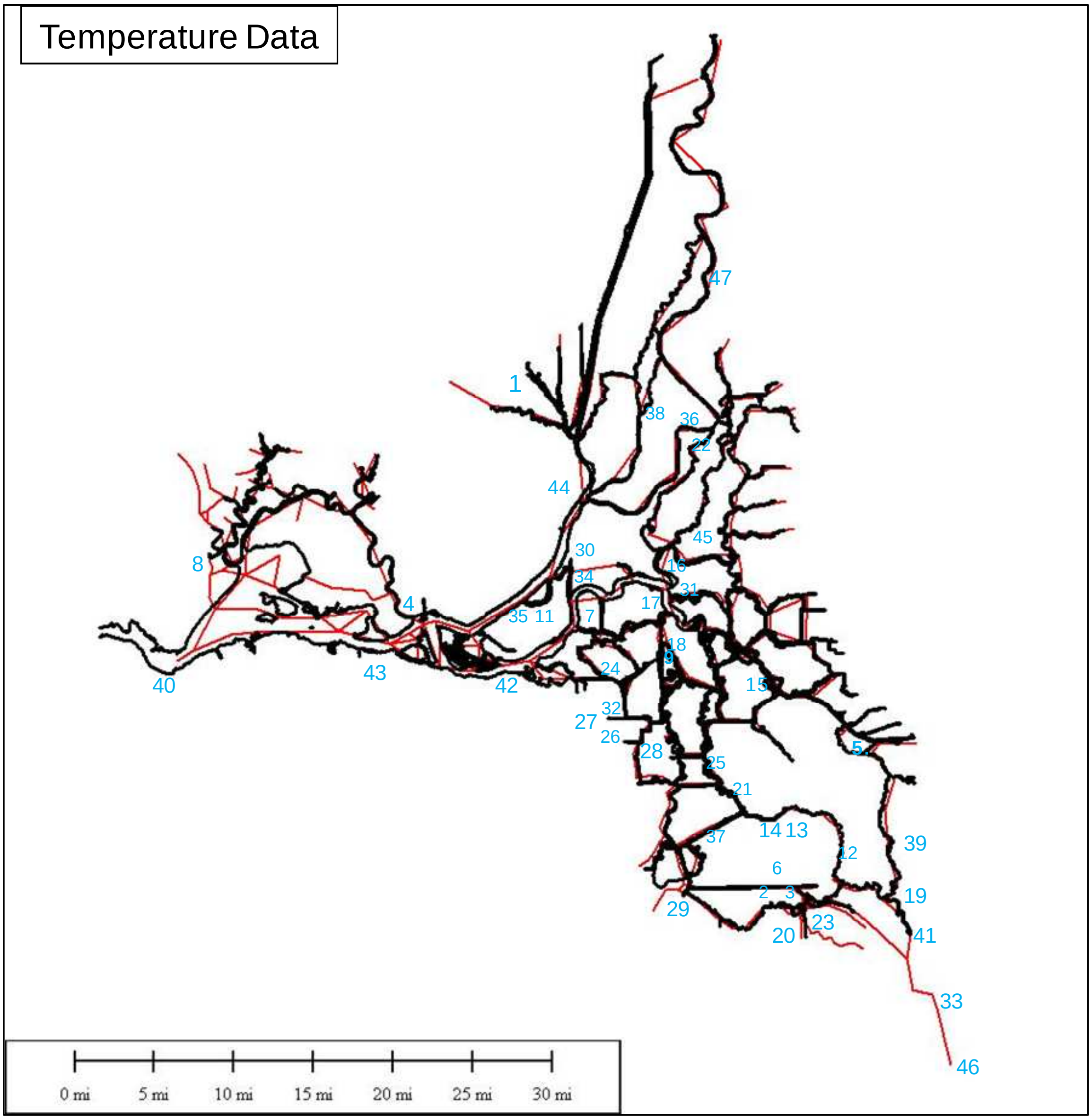


Figure 17-26 Locations of temperature data regular time series. Data quality and length of record is variable.

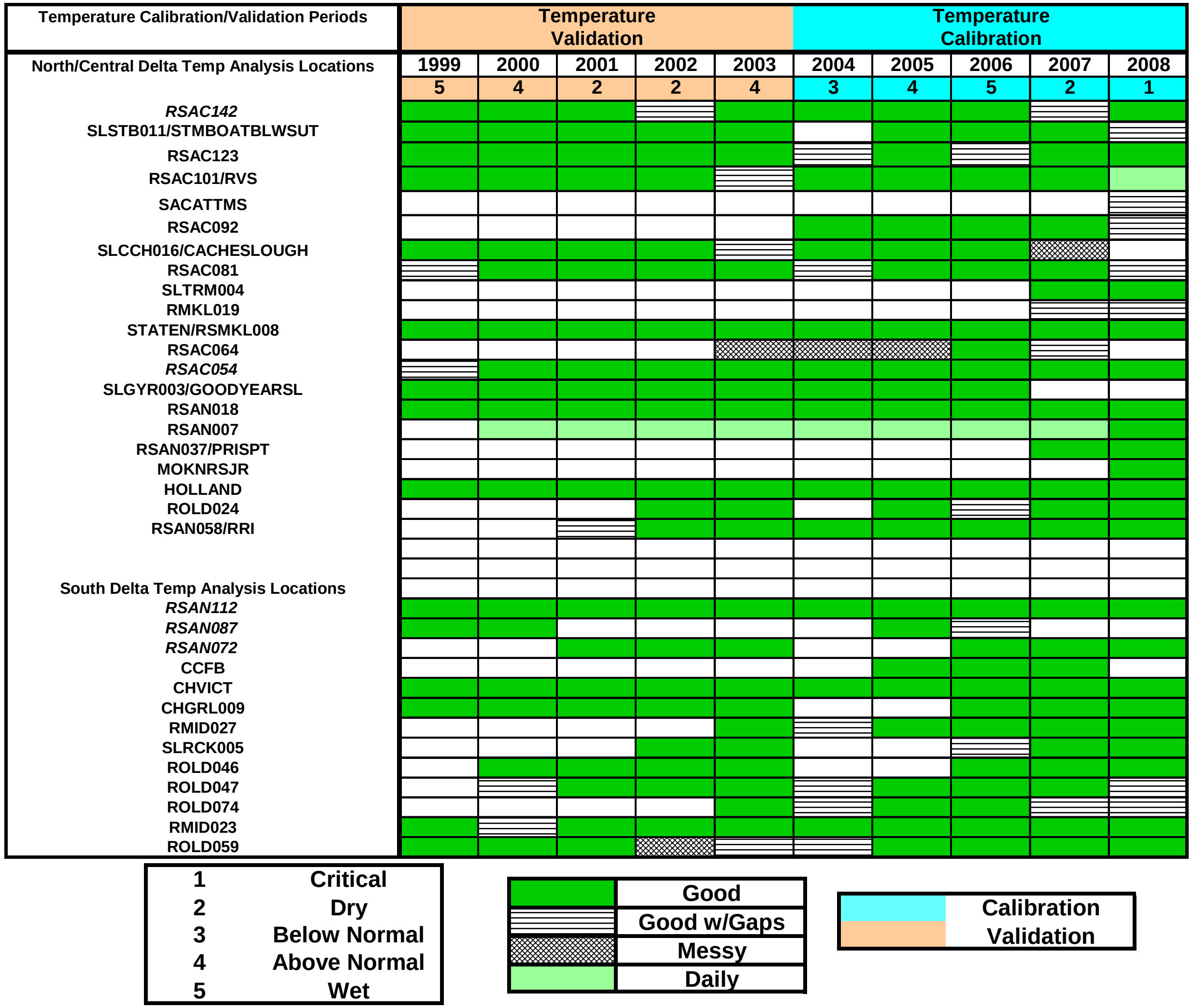


Figure 17-27 The coverage and quality of temperature data used in model or the years 1999 – 2008.

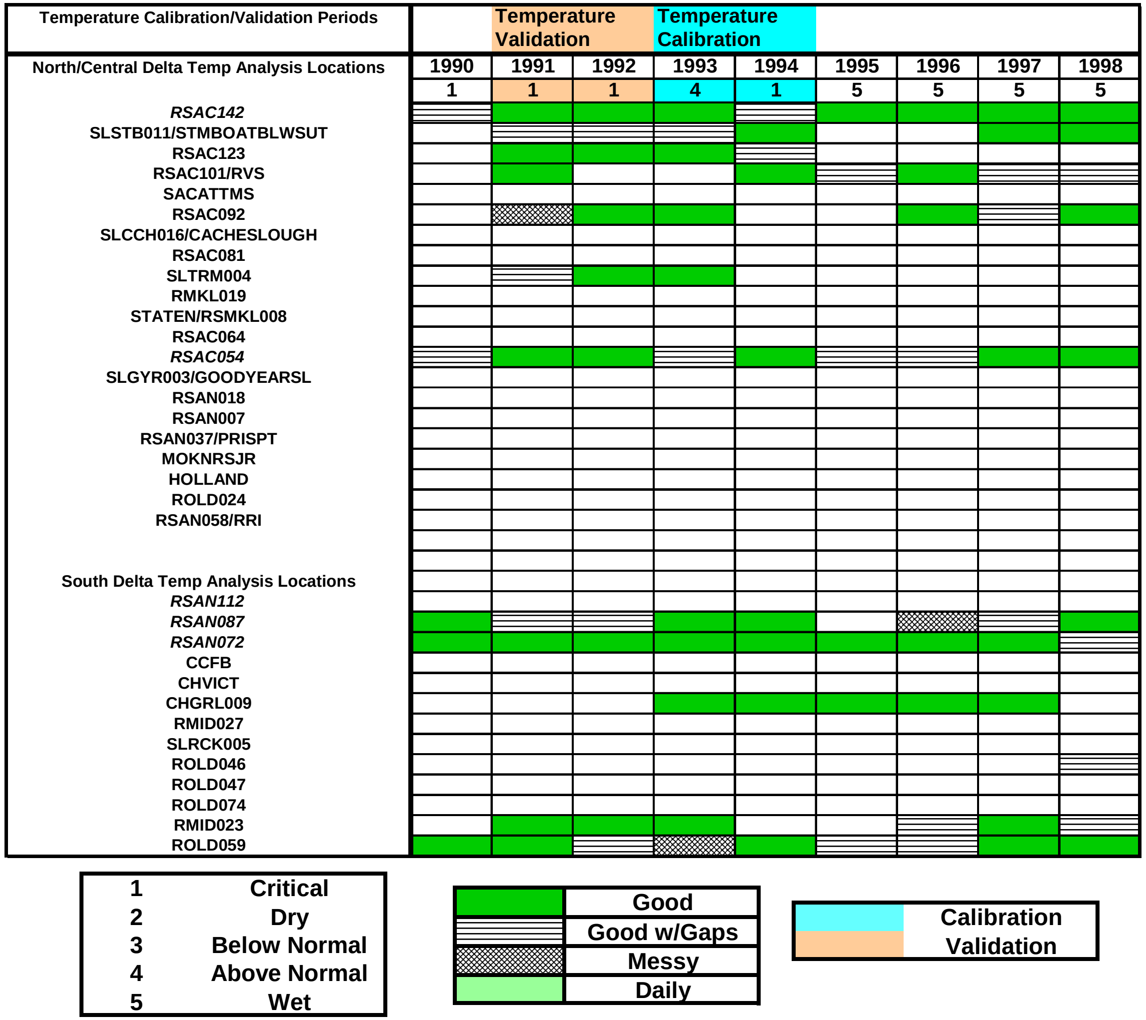


Figure 17-28 The coverage and quality of temperature data used in model for the years 1990 – 1998.

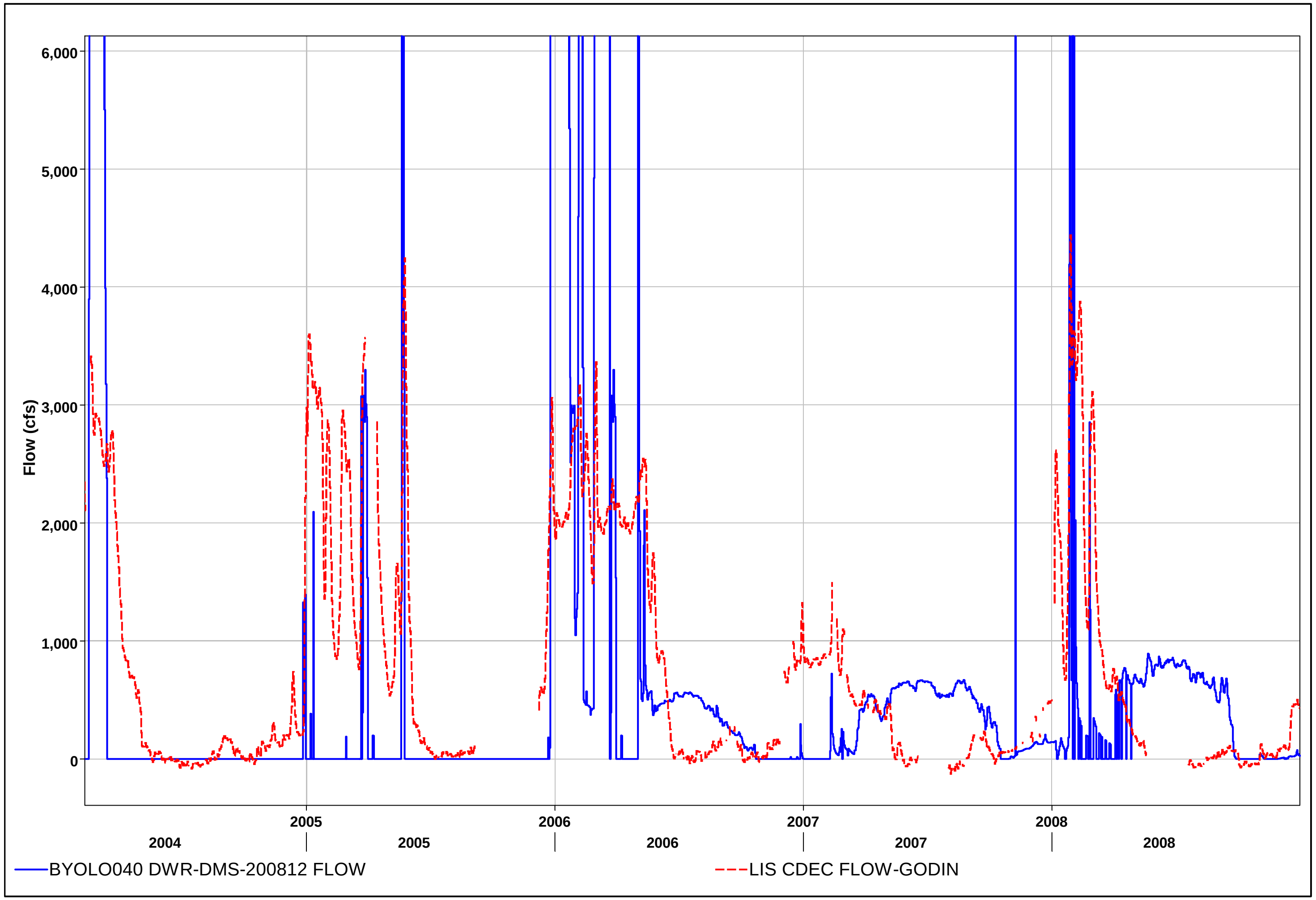


Figure 17-29 Flow data at the Lisbon Toe Drain (LIS, red line) and boundary condition data from DSM2 at the Yolo boundary (blue line).

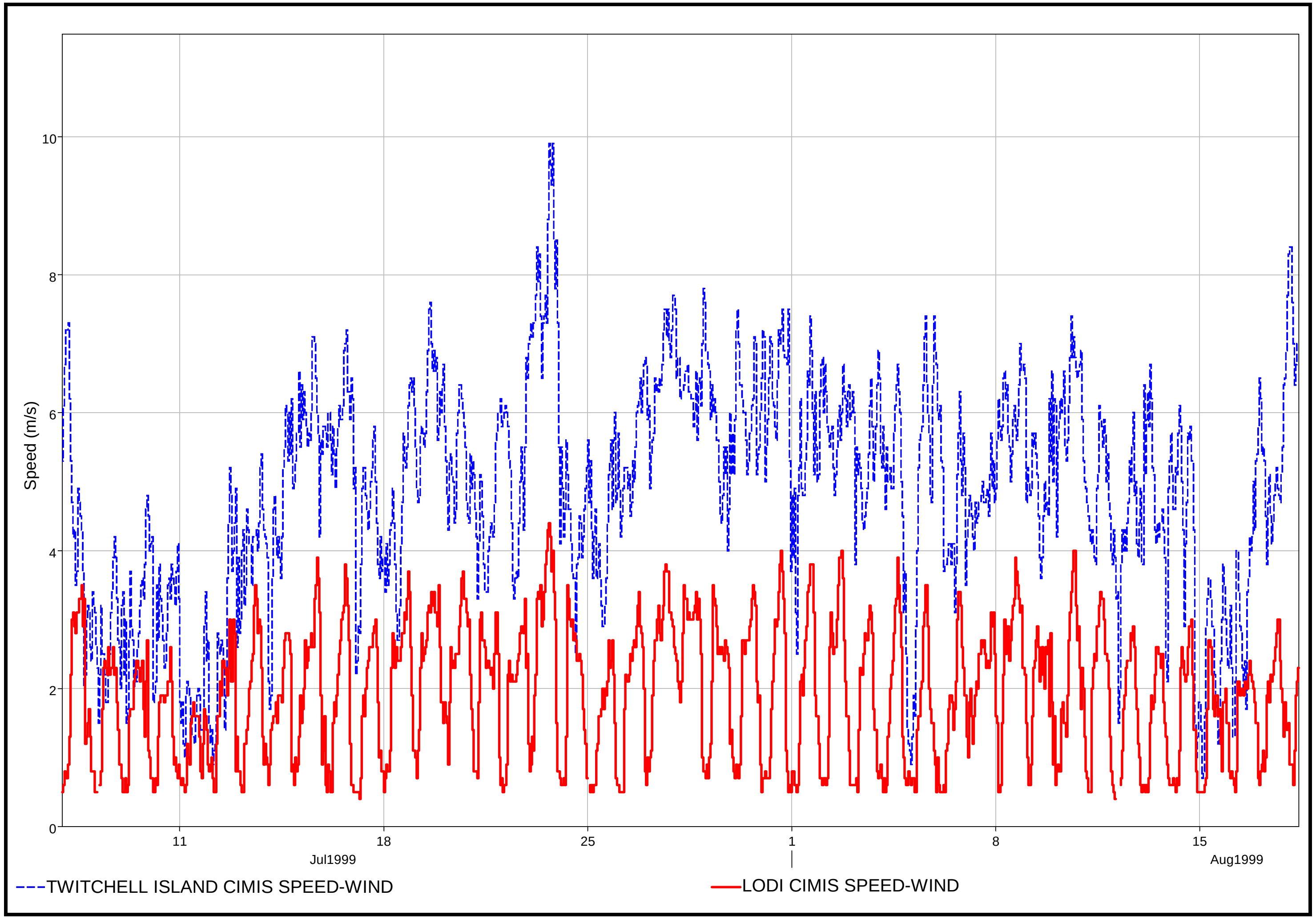


Figure 17-30 Wind speeds for the CIMIS stations at Lodi and at Twitchell Island show a factor of two difference in wind speed.

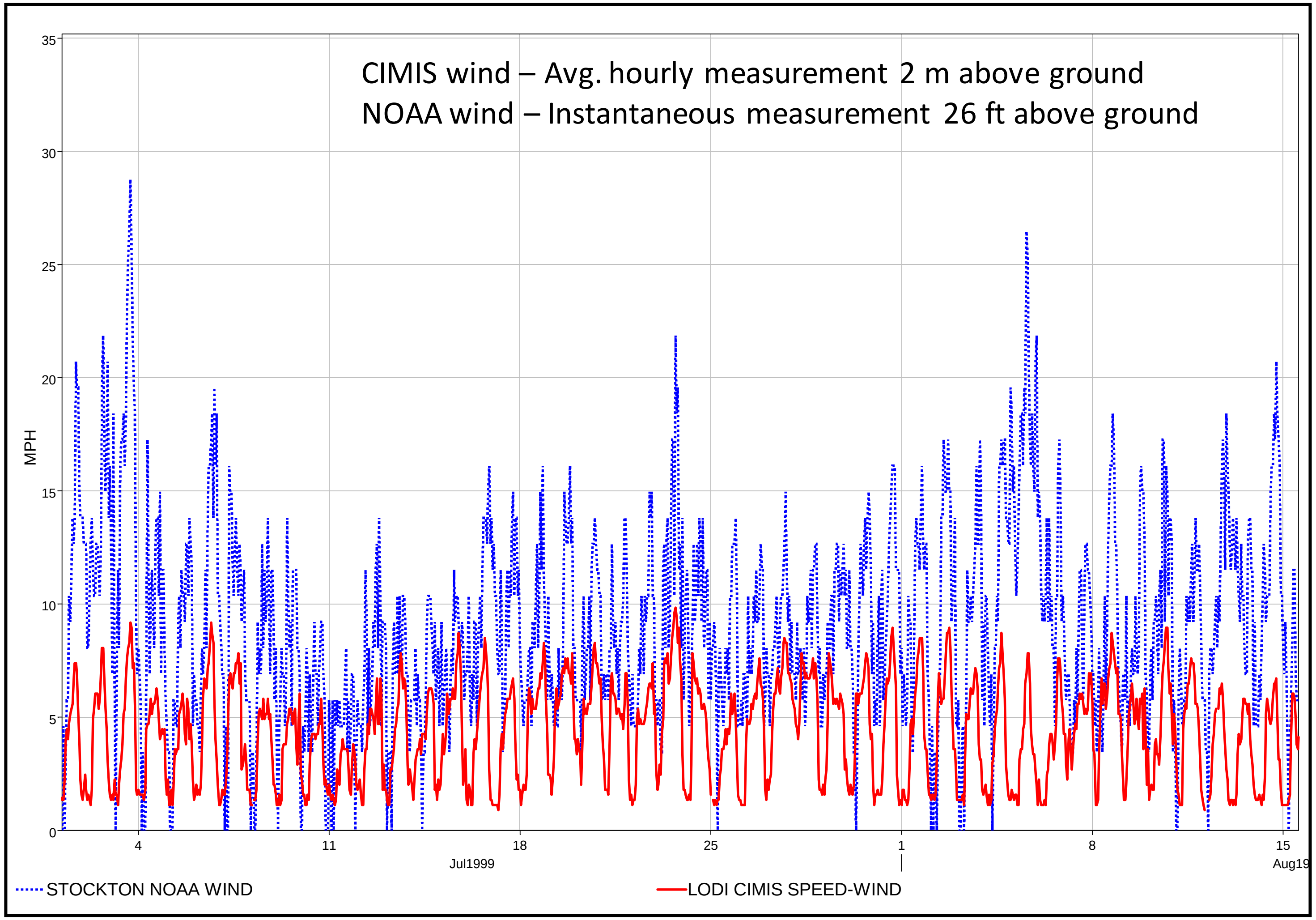


Figure 17-31 Wind speeds for the CIMIS station at Lodi and the NOAA station at Stockton show a factor two variation in reported speed.

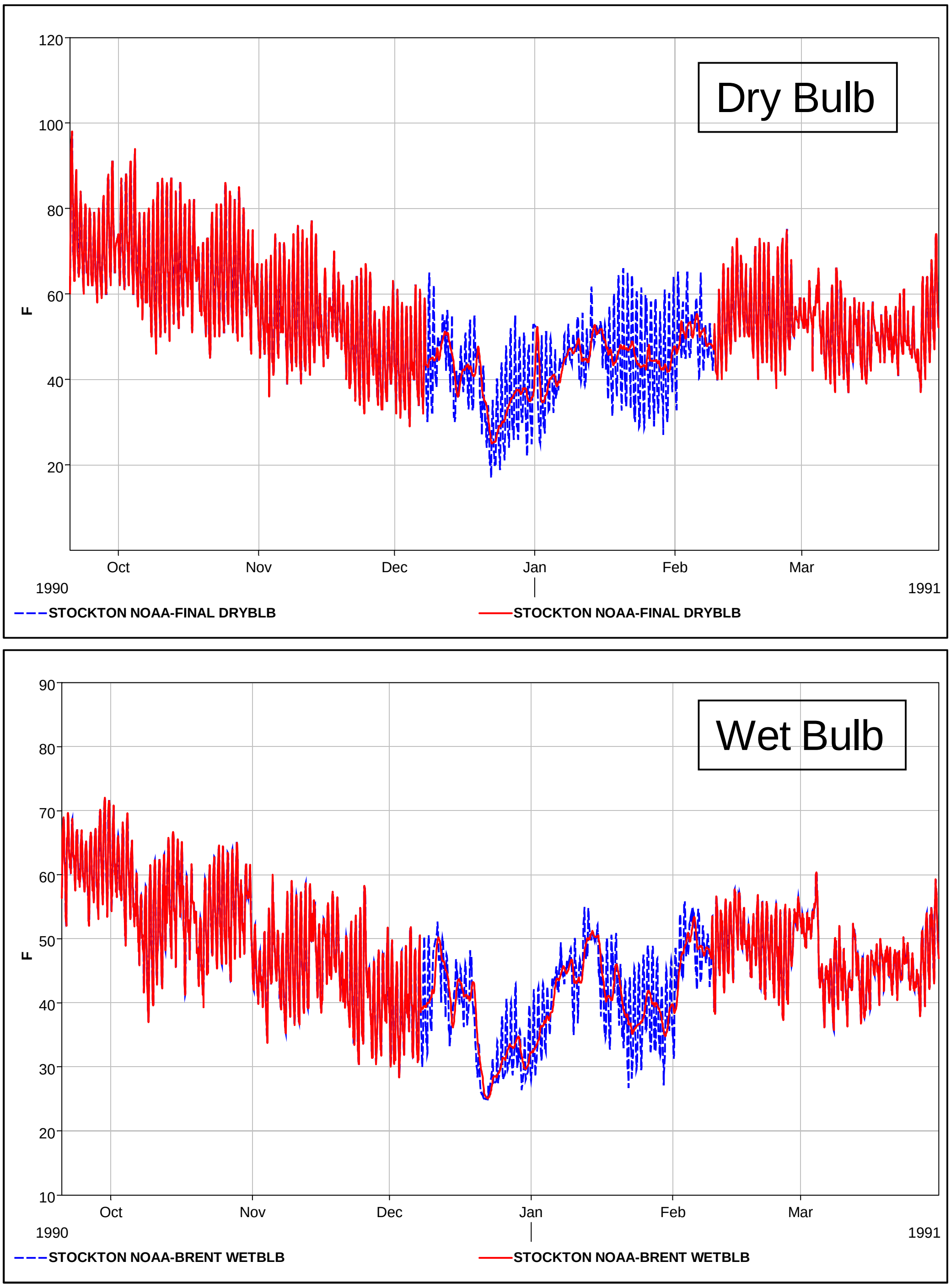


Figure 17-32 Red line is the smoothed boundary (dry bulb upper, wet bulb lower) used to get model convergence during these periods.

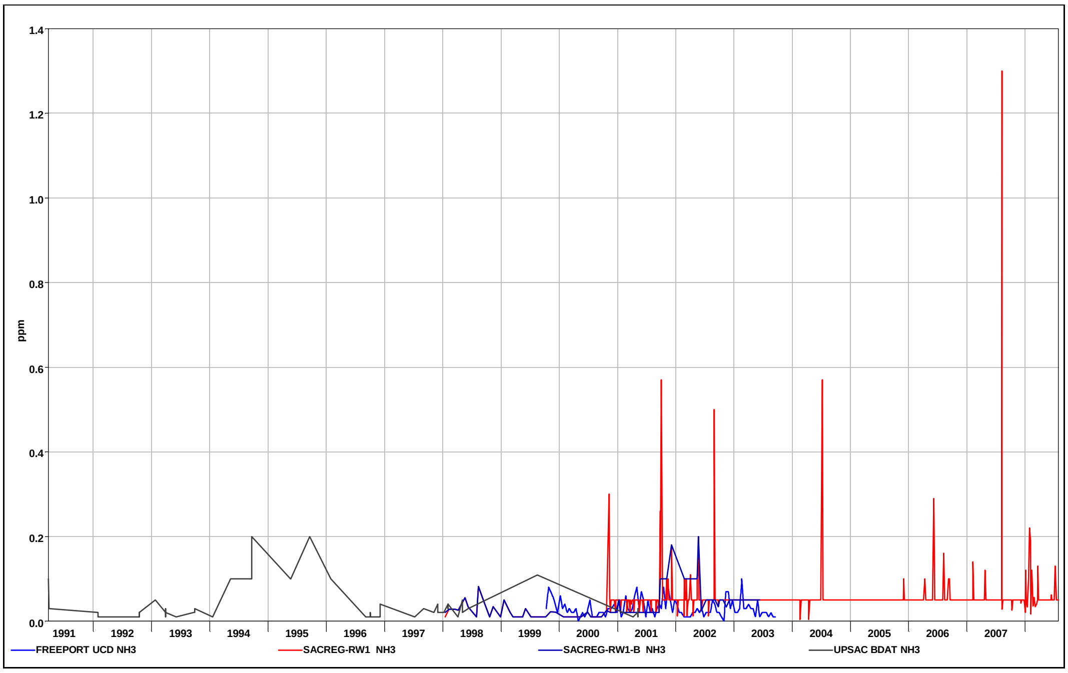


Figure 17-33 Ammonia concentration data above Freeport from three sources, UC Davis (blue), BDAT (black) and Sac Regional receiving waters monitoring (two data sets, red and dark blue).

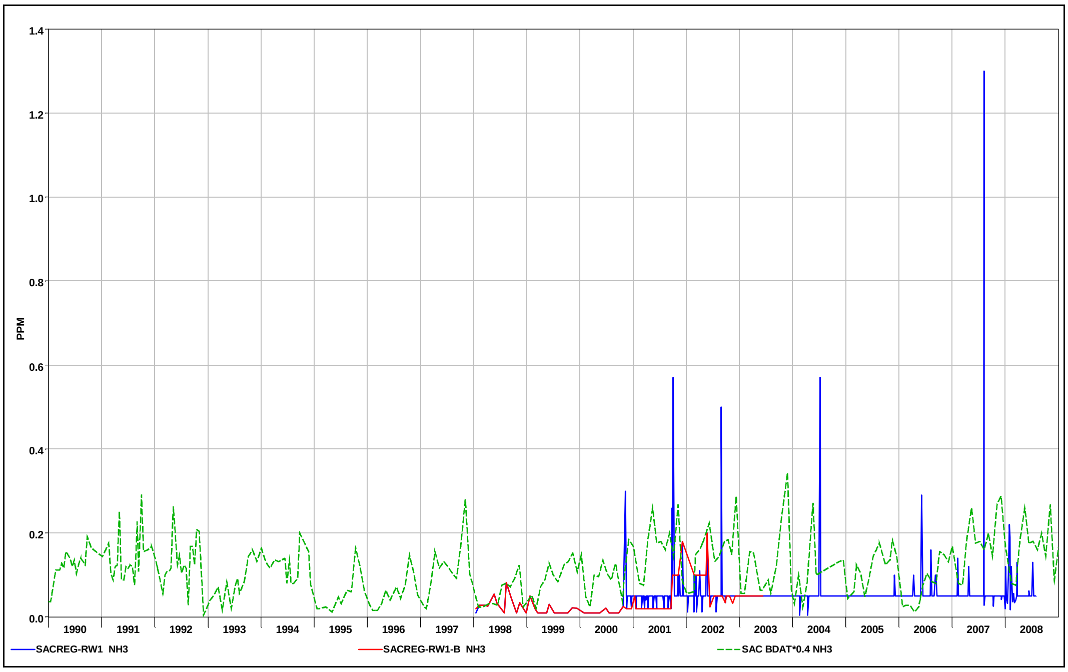
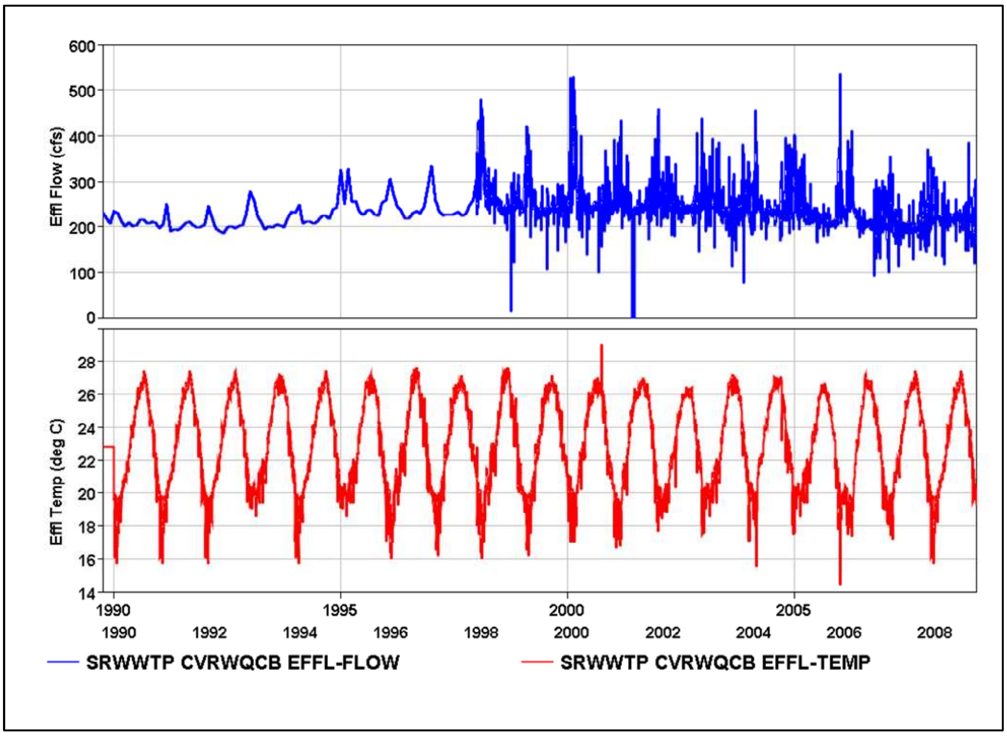


Figure 17-34 NH_3 concentration from Sac Regional receiving water measurements (blue and red) in comparison with NH_3 boundary condition set at BDAT Greens/Hood ammonia*0.4.



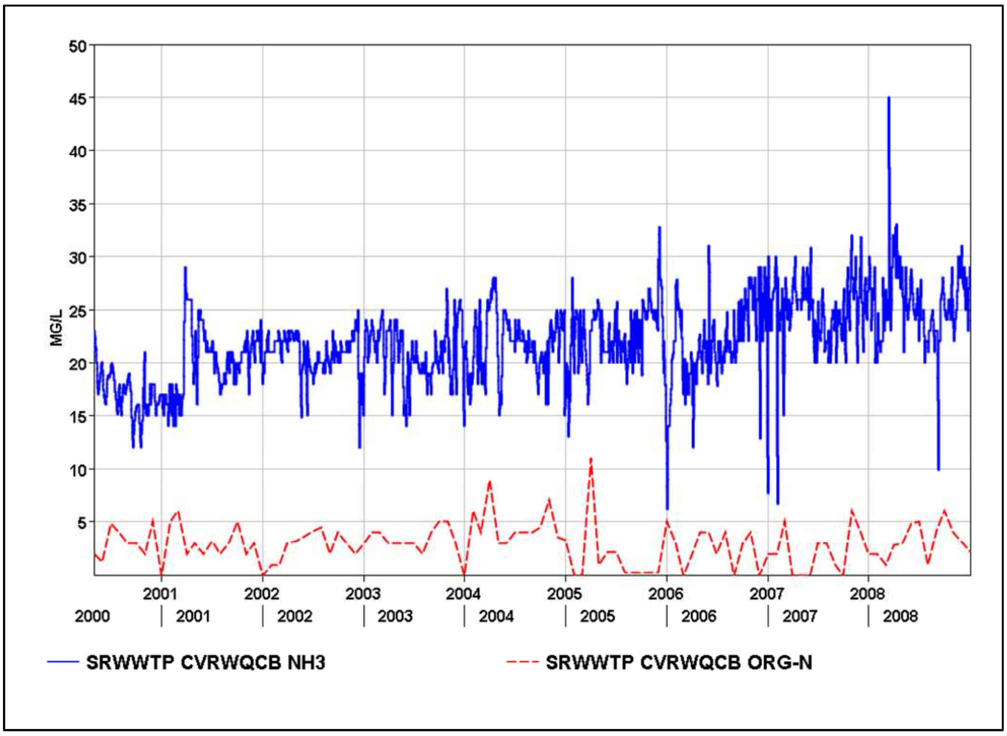
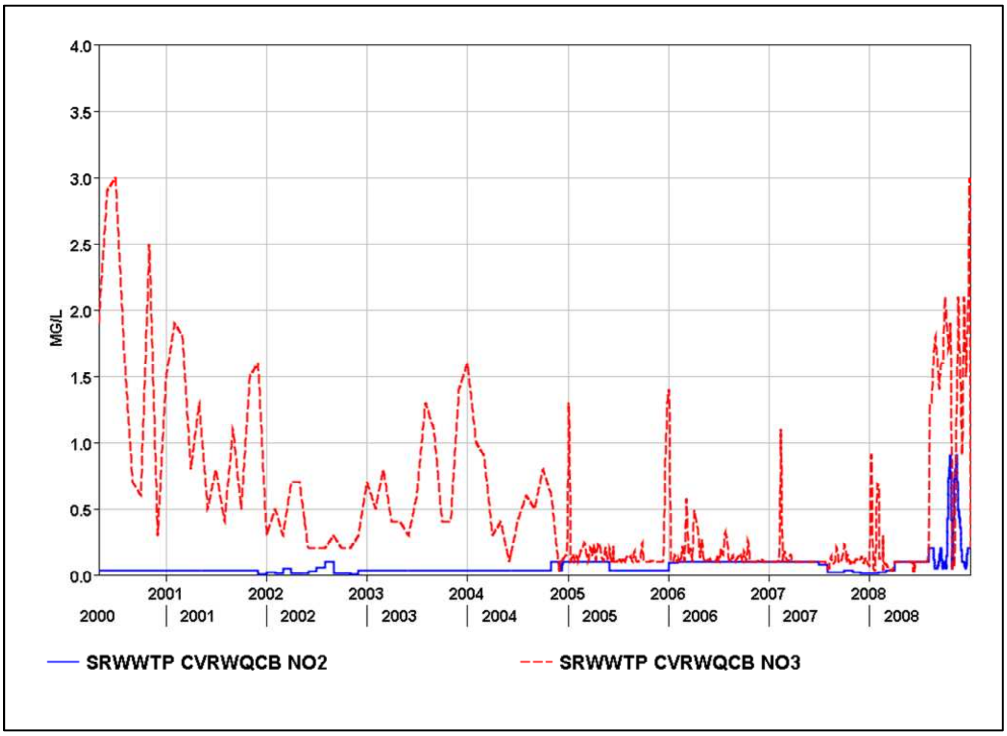


Figure 17-35 Sac Regional flow, temperature, ammonia and organic-N effluent concentrations.



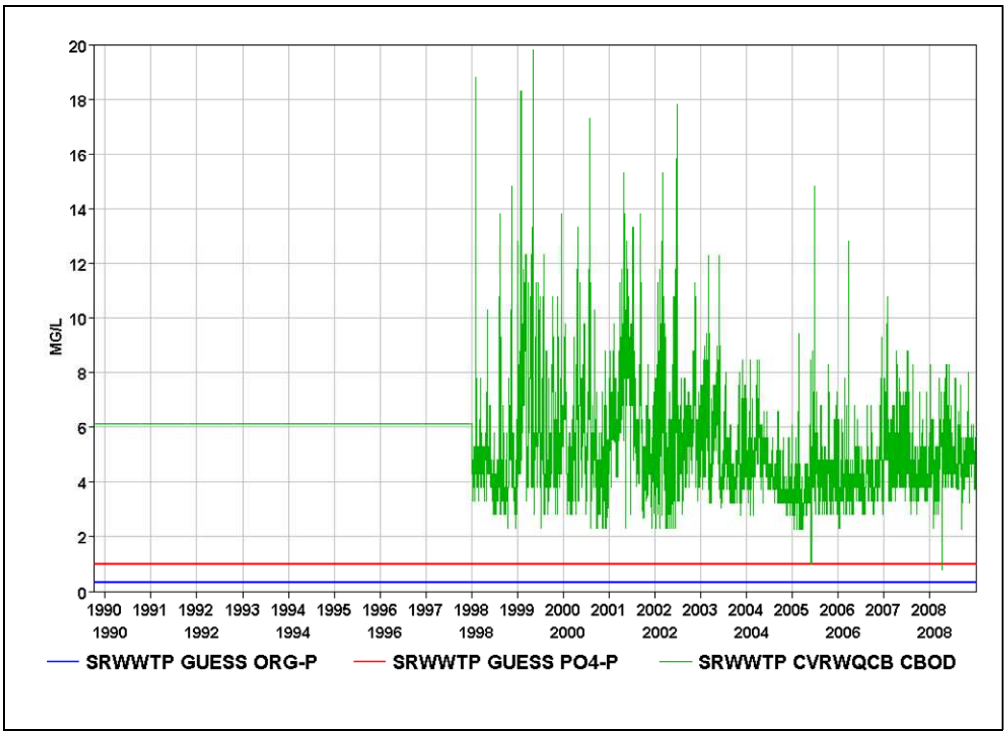


Figure 17-36 Sac Regional nitrate, nitrite, organic-P, CBOD and PO_4 effluent concentrations.

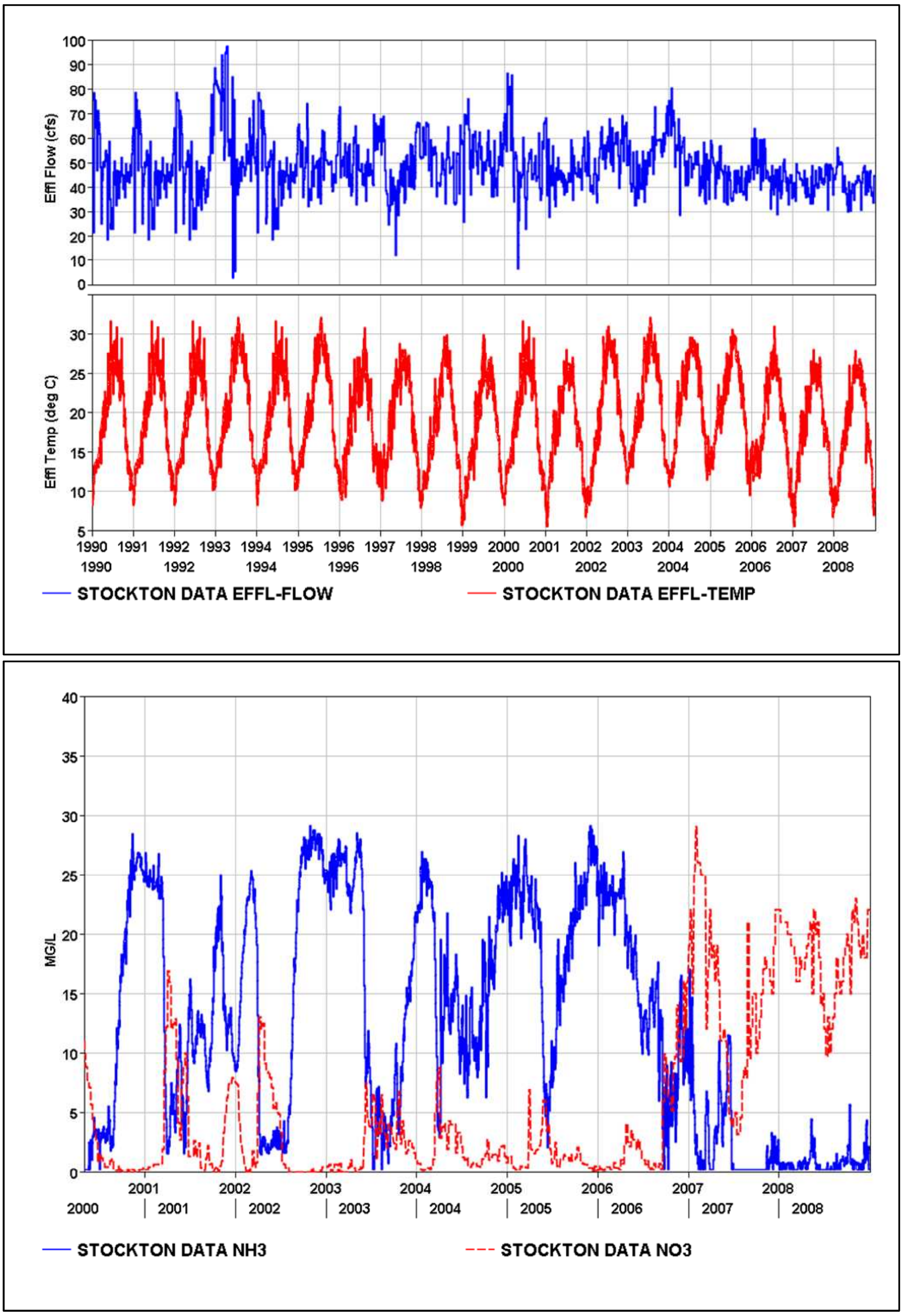
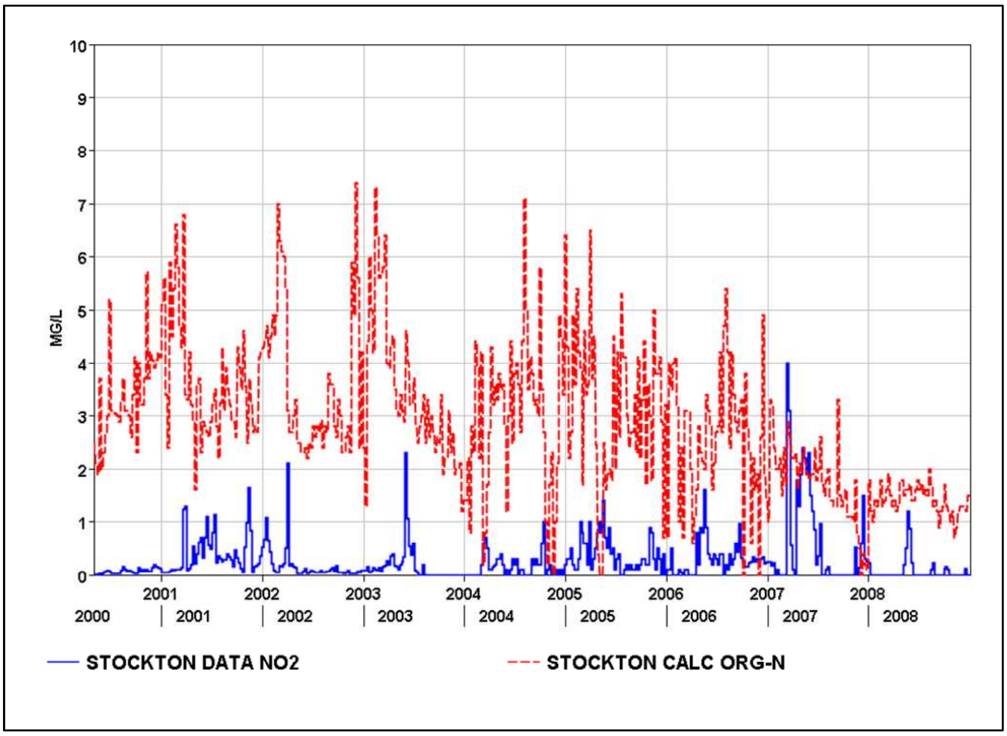


Figure 17-37 Stockton WWTP flow, temperature, ammonia and nitrate effluent concentrations.



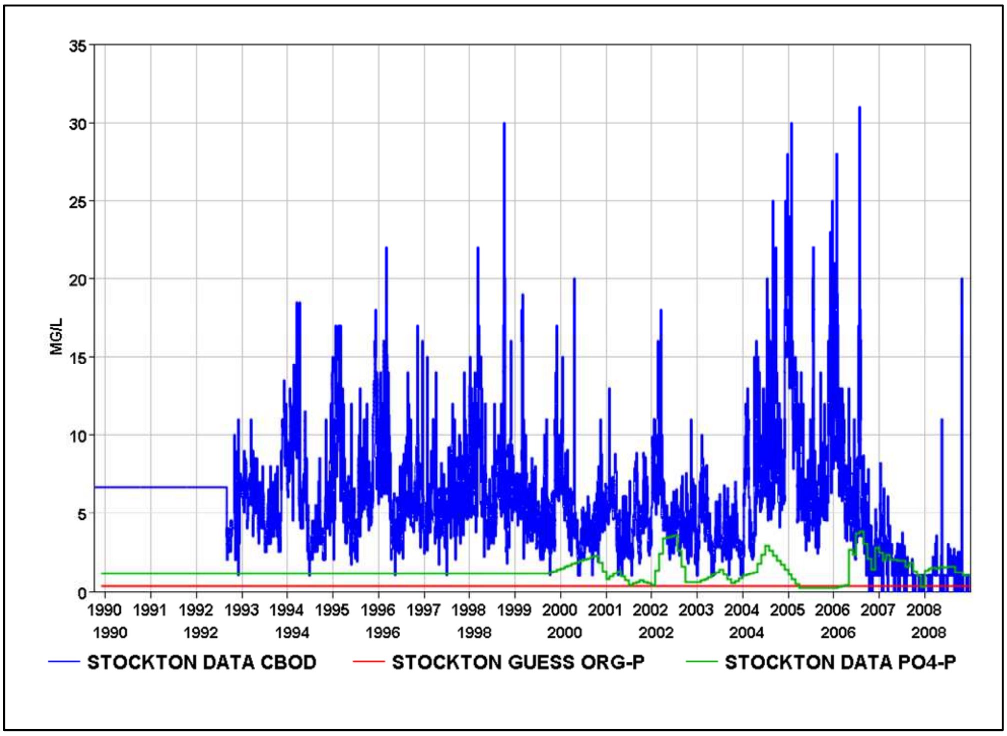


Figure 17-38 Stockton WWTP organic-N, nitrite, organic-P, CBOD and PO_4 effluent concentrations.

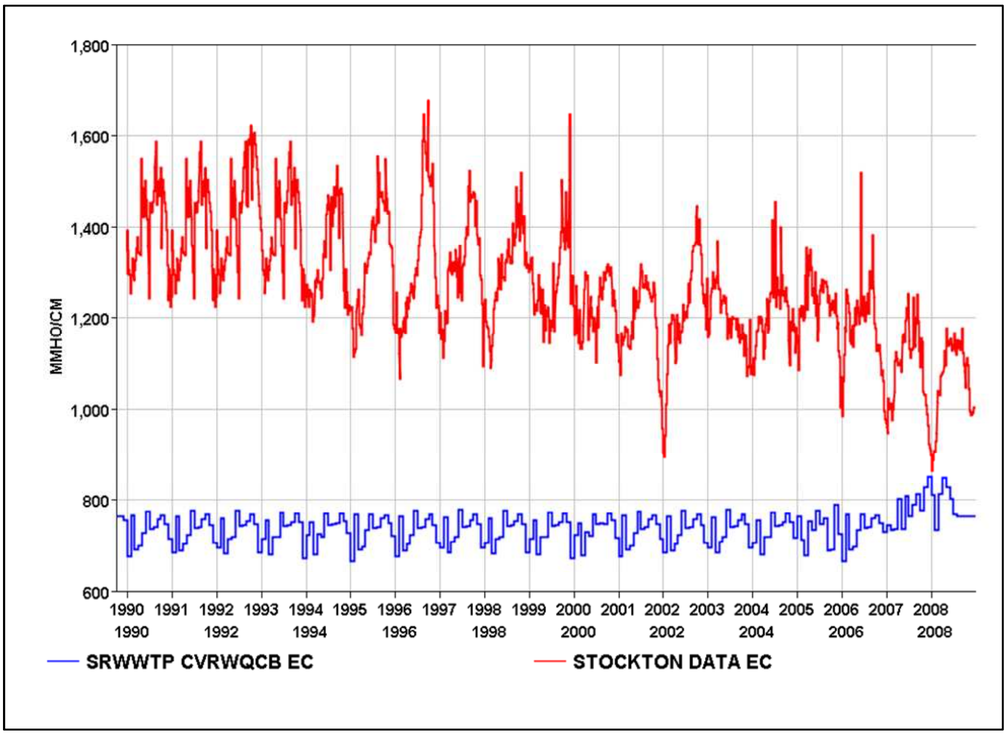


Figure 17-39 Sac Regional and Stockton WWTP effluent EC concentrations.

Table 17-7 Availability of measurements for seven WWTPs in the DSM2 model domain

Location	**Stockton** Tertiary since September 20'06	**Sac Regional** Secondary	**CCCSD** Secondary	**Delta Diablo** Secondary	**Tracy** Tertiary since July 2007	**Manteca** Tertiary since 06-08/03	**Lodi** Tertiary	**Fairfield-Suisun** Advanced secondary
Flow	mid-1992 - 2008	1990 - 2008	2000 - 2008	2004 - 2008	07/98 to 2008	04/04 to 08/08	05/00 - 07/06	2004 - 2008
Temp	1996 -2008, missing 2001, 2002	1998 - 2008	2000 - 2008	no data	07/98 to 2008	04/04 to 08/08	02/05 - 07/06	2004 - 2008
NH3	mid-1992 - 2008	1990 - 2008	2000 - 2008	03/04 to 2008	07/98 to 2008	05/04 to 08/08	05/00 - 07/06	03/04 to 2008
NO3	mid-1992 - 2008	1990 - 2008, missing short periods	2000 - 2008	no data	07/2007 to 2008	07/06 to 08/08	no data	10/07 to 2008
NO2	mid-1992 - 2008	2002 - 2008, missing segments	2000 - 2008	no data	07/2007 to 2008	07/06 to 08/08	no data	no data
Org-N	mid-1992 - 2008	1990 -2008, missing segments	2000 - 2008	no data	07/2007 to 2008	no data	no data	10/07 to 2008
BOD5	mid-1992 - 2008	1998 - 2008		no data	07/98 to 2008	04/04 to 08/08	05/00 - 07/06	2004 - 2008
CBOD	mid-1992 - 2008		2000 - 2008	no data				
PO4	mid-1992 - 2008	1998 - mid-08, missing segments	2000 - 2008	no data	no data	no data	no data	10/2007 to 2008
Org-P	no data	no data	no data	no data	no data	no data	no data	no data
DO	mid-1999 - 2008	no data	2000 - 2008	no data	no data	no data	02/05 - 05/06	no data
Chl-a	no data	no data	no data	no data	no data	no data	no data	no data
EC	mid-1992 - 2008	2004 - 2008	no data	no data	07/98 to 2008	09/05 to 08/08	05/00 - 07/06	no data
pH	mid-1993 - 2008	2000 - 2008	no data	no data	07/98 to 2008	04/04 to 08/08	02/05 - 07/06	2004 to 05/07

Table 17-8 Availability of measurements from the other WWTP's with effluent reaching the Delta. Vacaville, Davis and Woodland were not considered in this model. Benicia outfall is downstream of the model boundary.

Location	MTZ Refinery	Tesoro	Valero (Ben)	Benicia	Davis	Woodland	Vacaville	Disc. Bay	Mtn House
	(Biological treatment)	Refinery (Various treatments)	Refinery (Various treatments)		Secondary	Secondary		Secondary	Secondary (?) Mo Avg 05/04 - 06
Flow	2006 - 2008	2006 - 2008	2006 - 2008	2006 - 2008	2001 to 10-05	1996 - 2008	01/05 to 2008	2004 - 2007	Yes
Temp	no data	no data	no data	no data	2001 to 10-05	1996 - 2008	no data	2004 - 2007	Yes
NH3	2006 - 2008	2006 - 2008	2006 - 2008	few points	2001 to 10-05	1996 - 2008	no data	2004 - 2007	Yes
NO3	no data	no data	no data	no data		1996 - 2008	12/04 - 11/07	2004 - 2007	Yes
NO2	no data	no data	no data	no data	no data	no data	12/04 - 11/07	no data	Yes
Org-N	no data	no data	no data	no data	no data	no data	no data	no data	No
BOD5	no data	no data	no data	no data	2001 to 10-05	1996 - 2008	no data	2004 - 2007	No
CBOD	no data	no data	no data	no data			no data		No
PO4	no data	no data	no data	no data	no data	1996 - 2008	(TOT-P)	no data	Tot-P
Org-P	no data	no data	no data	no data	no data	no data	no data	no data	No
DO	no data	no data	no data	no data	no data	no data	no data	2004 - 2007	No
Chl-a	no data	no data	no data	no data	no data	no data	no data	no data	No
EC	no data	no data	no data	no data	2001 to 10-05	1996 - 2008	12/04 - 11/07	2004 - 2007	Yes
pH	no data	no data	no data	no data	2001 to 10-05	1996 - 2008	12/04 - 11/07	2004 - 2007	Yes

17.7 Wet Bulb Temperature Calculations

Because wet bulb temperature is used in the model and data were not available prior to 1996, an algorithm was used to calculate wet bulb temperature derived from relationships between saturated vapor pressure, relative humidity or dew point and air temperature.

Relative humidity is defined as the ratio of the ambient vapor pressure to the saturated vapor pressure (100 % humidity). The dew point is the temperature that corresponds to the ambient vapor pressure. The wet bulb temperature is the temperature measured by an apparatus that relies on evaporated cooling that is a function of humidity, high wind speed and atmospheric pressure. The wet bulb temperature always falls between the ambient temperature and the dew point.

Saturated vapor pressure can be computed using the following fit of physical data:

$$VP_s = 2.1718\ e^{8} * e^{(-4157/Ta)} \tag{A1}$$

Where VP_s is the saturated vapor pressure in millibars and T_a is the air temperature in degrees Kelvin (°C+239.09).

If air temperature is available, then vapor pressure can be computed if relative humidity, dew point or wet bulb temperature is available. Assuming that the dew point is available, the ambient humidity can be computed which yields the relative humidity. Assuming relative humidity is available; the ambient vapor pressure may be computed as relative humidity (fractional) times "VP_s" and then the dew point can be computed.

A simple approach was used to compute dew point. Air temperature "T_a" was incremented (in steps of 0.025 °C in this application) using equation (A1) until the difference between the ambient and computed vapor pressure was minimized.

Given the dew point temperature (observed or computed), the following expression, derived from a fit of physical data, defines the vapor pressure at the wet bulb temperature as:

$$VP_s = 2.1718\ e^{8} * e^{(-4157/Ta)} - P*(T_c-T_w)*(6.6\ e^{-4} + (7.59\ e^{-7}) * T_w) \tag{A2}$$

where T_c is the air temperature in degrees Celsius, P is the atmospheric pressure in millibars and T_w is the air temperature in degrees Celsius.

A simple approach was also used to compute the wet bulb temperature by incrementing "T_w" (in increments of 0.025 °C) of the above equation until the difference between the ambient and computed vapor pressure was minimized.

17.8 Methodology for Setting Sacramento River NH_3 and NO_3 Boundary Conditions

Data to set the NH_3 boundary condition (BC) on the Sacramento River was obtained from a variety of sources, including Sac Regional receiving water measurements, MWQI and a dataset from R. Dahlgren at UC Davis. The ammonia data, as seen from are sparse, generally range from 0.01 mg/L to a maximum of about 1.3 mg/L, and are quite variable between measurement agencies as shown in Figure 17-33.

Figure 17-34 shows a comparison of Sac Regional receiving water measurements near Freeport and the boundary condition for ammonia set using merged BDAT data from Greenes Landing and Hood, but reduced by a factor 0.4. Although the ranges of the data values shown in Figure 17-33 are comparable for the different agencies, particularly at maximum values, these data suggest that the ammonia boundary condition shown in Figure 17-34 at the Sacramento River boundary is frequently high. Note that the detection level of ammonia for the Sac Regional receiving water dataset varies, although it was frequently quoted as 0.1 mg/L. For the purposes of comparisons in plotting, the plotted value was set at (detection limit)/2 on dates where a measurement was taken but below the specified limit.

Several strategies were used to develop a revised Sacramento R. ammonia BC. Several of these strategies are illustrated in figures, below. A straight-forward mass balance approach[18] is shown in Figure 17-40 in comparison with the boundary condition (blue) set at (Greens/Hood ammonia)*(0.4). The boundary concentration values calculated using this simple mass balance approach are frequently negative – negative values have been suppressed in the figure. A variation on this approach was used for the calculation shown in Figure 17-41 to avoid negative values – the Sac Regional receiving water data is shown for comparison (red line). In this case, scaling factors were applied in the calculation to lower the effluent ammonia concentration and the overall concentration at the Sac R. boundary.

The effect of the Sacramento flow magnitude was also investigated - some results are shown in Figure 17-42 and in Figure 17-43 in comparison with Sac Regional receiving water data (Figure 17-42, green) and with the UC Davis data (Figure 17-43, green). In the “low flow” case, the boundary value was set at 0.015 mg/L below 10,000 cfs Sacramento R. flow, and otherwise at 0.015 mg/L plus an additional factor of 15% of the scaled mass-balance ammonia calculation. In the “high flow” case, above 60,000 cfs Sacramento R. flow, the value was calculated at 0.015 mg/L plus 15% of the mass balance ammonia and at 0.015 mg/L otherwise. In both of these

[18] (Final Concentration*Final Volume) = (Concentration at BC)*(Volume BC) + (Concentration Effl * Volume Effl) Solve for Concentration at BC.

cases, the components in the mass balance calculation were altered by constant scaling factors to improve the fit.

None of the calculations give a clear-cut best fit for the measured ammonia near Freeport, so the high flow case was selected to test as a boundary condition in the nutrient model as it captured some of the variability in the UC Davis dataset. Figure 17-44 and Figure 17-45 illustrate results for modeled ammonia concentration at three locations downstream of the Sacramento R. boundary. Figure 17-44 (upper plot) is a comparison of two models with results at RSAC139 (Greens Landing) – the models were run with different Sacramento R. ammonia BC's. The blue lines are the modeled monthly MAX and MIN envelope (of hourly results, see Section 10.3) for the calculated "high flow" case, denoted the V12 model run. The red lines are the MAX and MIN envelope of the V11 model run with the Sac R. BC set at (Greens/Hood ammonia)*(0.4). Figure 17-44 (lower) shows the V12 results at RSAC139 (Greens Landing) for both the Greens and Hood EMP data over a longer time span. Figure 17-45 shows the V12 ("high flow") Max and Min envelope model results for ammonia at Point Sacramento (upper) and at Potato Point (lower) in comparison with data (green symbols).

Although Figure 17-42 shows that the difference in values between these two boundary conditions ranged between no difference and a factor of four increase (with the Greens/Hood*0.4 values generally higher than the calculated high flow case), there is much less difference in the modeled envelopes between the two models (Figure 17-44, upper). The two model runs would be deemed nearly equivalent in terms of the calibration. This result is generally consistent with the Sac R. ammonia BC sensitivity runs (+/- 20% in BC value) for an earlier set of boundary conditions, where the differences were also not large.

The situation for the Sacramento River nitrate boundary condition was simple in comparison with the ammonia BC. Figure 17-46 and Figure 17-47 show comparisons between different nitrate datasets near Freeport and with the nitrate BC set using the EMP data at Greens/Hood reduced by a factor of 0.825, respectively. The variability in the datasets is small (Figure 17-46), and the nitrate BC was set at a value that is consistent with the data (Figure 17-47).

The conclusions from this analysis are mixed. Because the data for ammonia near the model boundary are quite variable, and only partially consistent between data-gathering agencies, this leads to a high level of uncertainty in the setting of the ammonia boundary condition for the Sacramento R. The final four plots illustrate the implications of this observation.

An additional simulation was run with a constant Sacramento R. ammonia BC – the concentration was set at 0.05 mg/L which is the (higher) Sac Regional detection limit for ammonia*0.5. Note that Freeport (RSAC155) is below the model boundary for Sacramento inflow. Figure 17-48 shows a comparison between the V12 model run ("high flow"), the constant concentration boundary condition and the UC Davis measured ammonia concentration near Freeport. The modeled ammonia for the constant concentration run has changed from the constant boundary value due to algal growth and decay of ammonia from the parameterization for this region. The V12 model boundary condition was selected because it had some resemblance to the UC Davis data at Freeport, and this resemblance is maintained at Freeport, while the constant concentration boundary has too little variability in comparison with the UC Davis data.

Figure 17-49 shows a comparison of the same two models, constant concentration boundary and V12 (“high flow”), plotted with the Sac Regional receiving water data near Freeport. In this case, neither model appears to yield a suitable representation of the data, as the variability in the data is much greater than the models produced, although the V12 “high flow” model does catch some of the dips in the receiving water measurements.

Figure 17-50 shows that at Greens Landing, RSAC139, the choice of the constant concentration boundary or the calculated “high flow” mass balance approach is immaterial – they are nearly identical. The final comparison, Figure 17-52, is comparison of EMP ammonia data measured at Greens landing with three model runs - constant concentration (green dash), V12 “high flow” (red), and V10 with the Sacramento boundary set at (Greens/Hood ammonia)*(0.4) (blue dash) – showing that each of the three Sacramento R. ammonia BC settings gives a good representation of this sparse calibration dataset, although all but the V10 model run tend to be low in comparison with the Greens Landing data.

The final observation from the data analysis was that negative values produced during of the mixing model calculations for BC NH_3 were apparently related to the ratio:

Flow ratio = (Total Sac flow)/ Sacramento R. inflow)

as shown in Figure 17-51, where the value

Total Sac flow = Sacramento R. BC inflow + Sac Regional effluent flow.

Following this observation, the final mixing model formula for the Sacramento NH_3 BC was set as:

(Total Sac flow)*(NH_3 Grns/Hood) – (Sac Reg Effl flow)*(Effl NH_3)*0.8 / (Total Sac flow)*(Flow ratio)

Any remaining negative values in this time series were then set to 0.025 mg/L, and the factor of 0.8 was used to account for reactions between the outfall and the measurement point at Greenes/Hood.

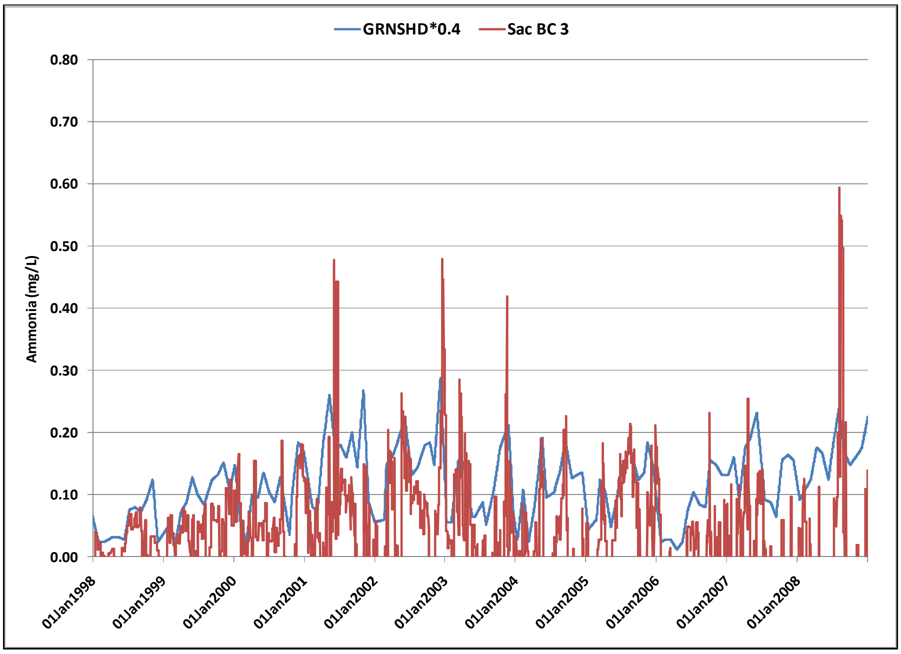


Figure 17-40 Sacramento R. NH_3 boundary condition (red) calculated using a mass balance approach in comparison with previous boundary condition (blue).

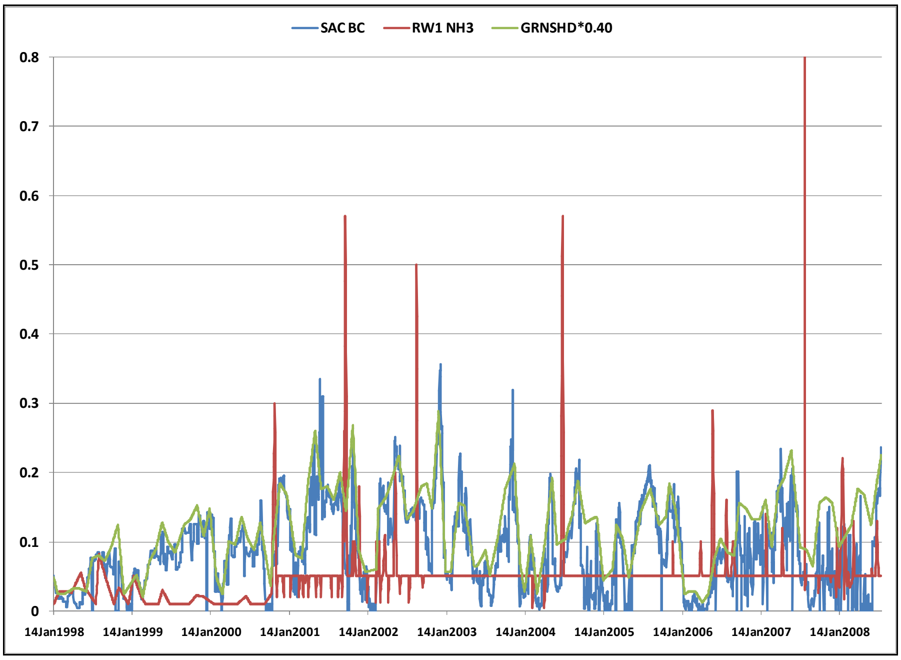


Figure 17-41 Sacramento R. NH_3 boundary (blue) calculated using a revised mass balance approach in comparison with Sac Regional receiving water NH_3 data (red) and previous boundary condition (green).

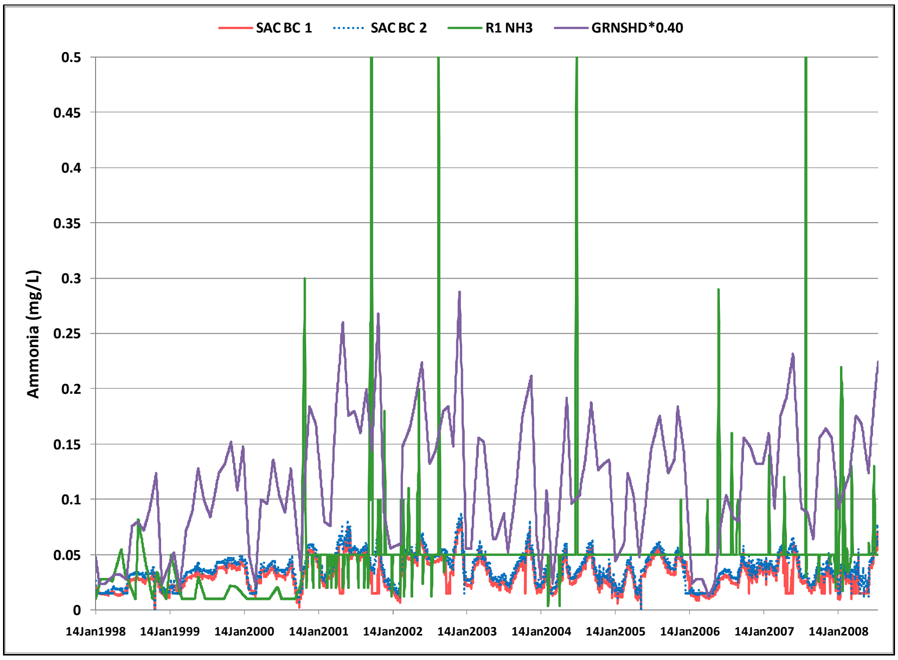


Figure 17-42 Two calculated NH_3 boundary conditions: low flow (red) and high flow (blue) constraint with a minimum value compared with Sac Regional receiving water NH_3 (green) and previous BC (purple).

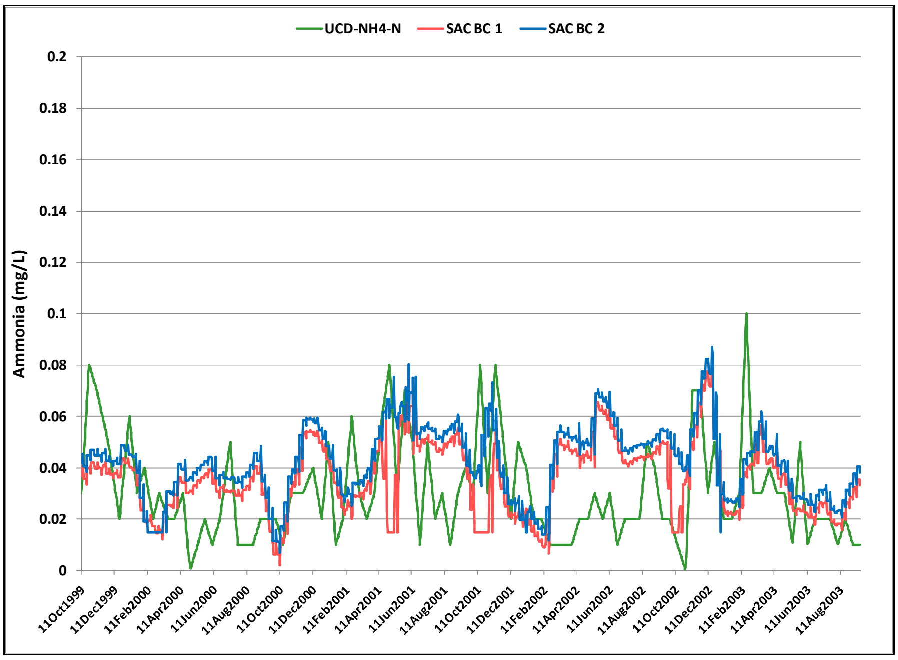


Figure 17-43 The same two calculated boundary conditions as in Figure 17-42, in comparison with UC Davis Freeport measured ammonia (green)

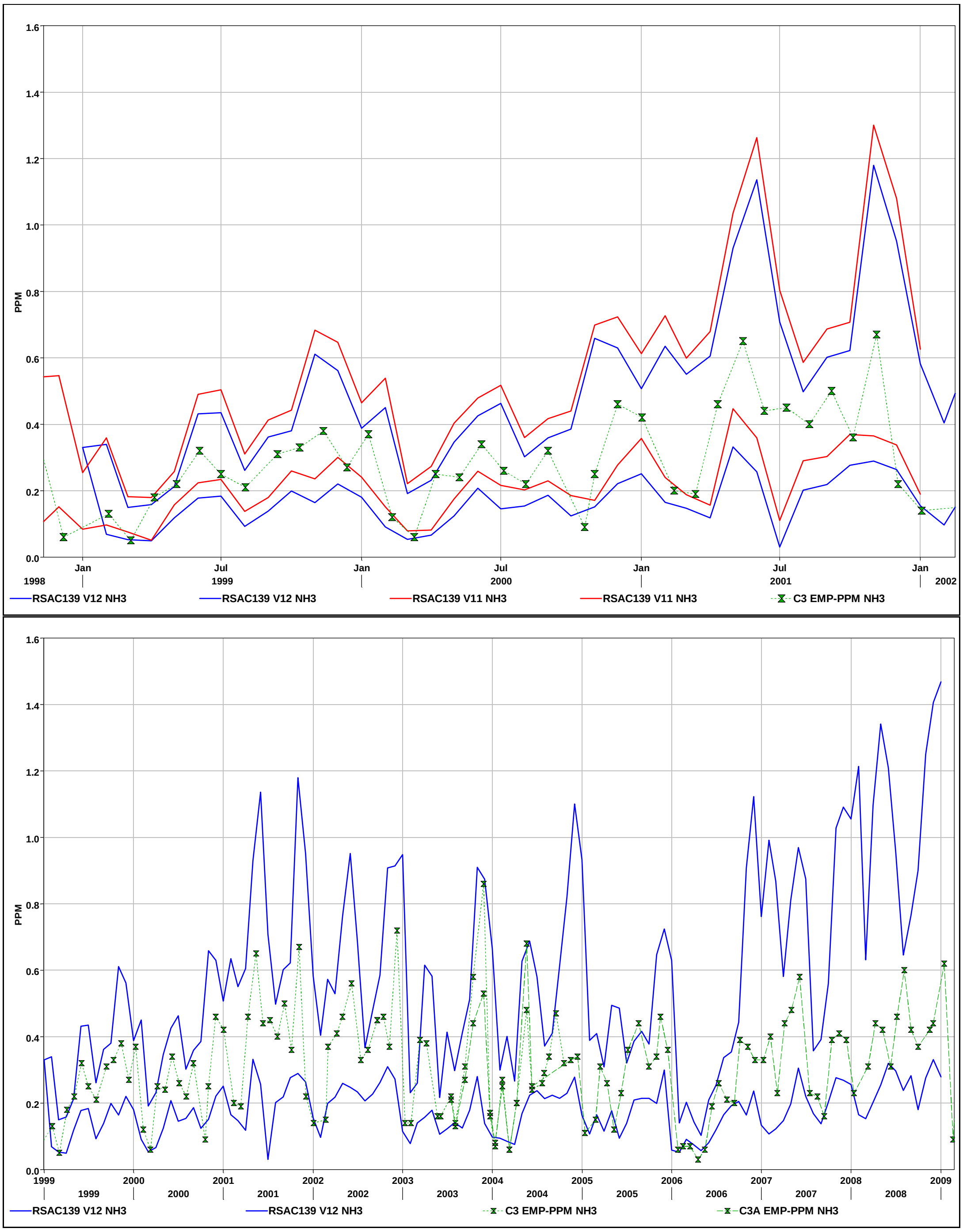


Figure 17-44 Modeled (blue) and measured (green symbol) ammonia at Greens Landing (RSAC139). Upper: Model V12 Sac R. BC with high flow constraint; V11 (red) with a GRNSHOOD*0.4 BC. Lower: V12 model output at Greenes Landing vs. Greenes (C3) and Hood (C3A) ammonia data.

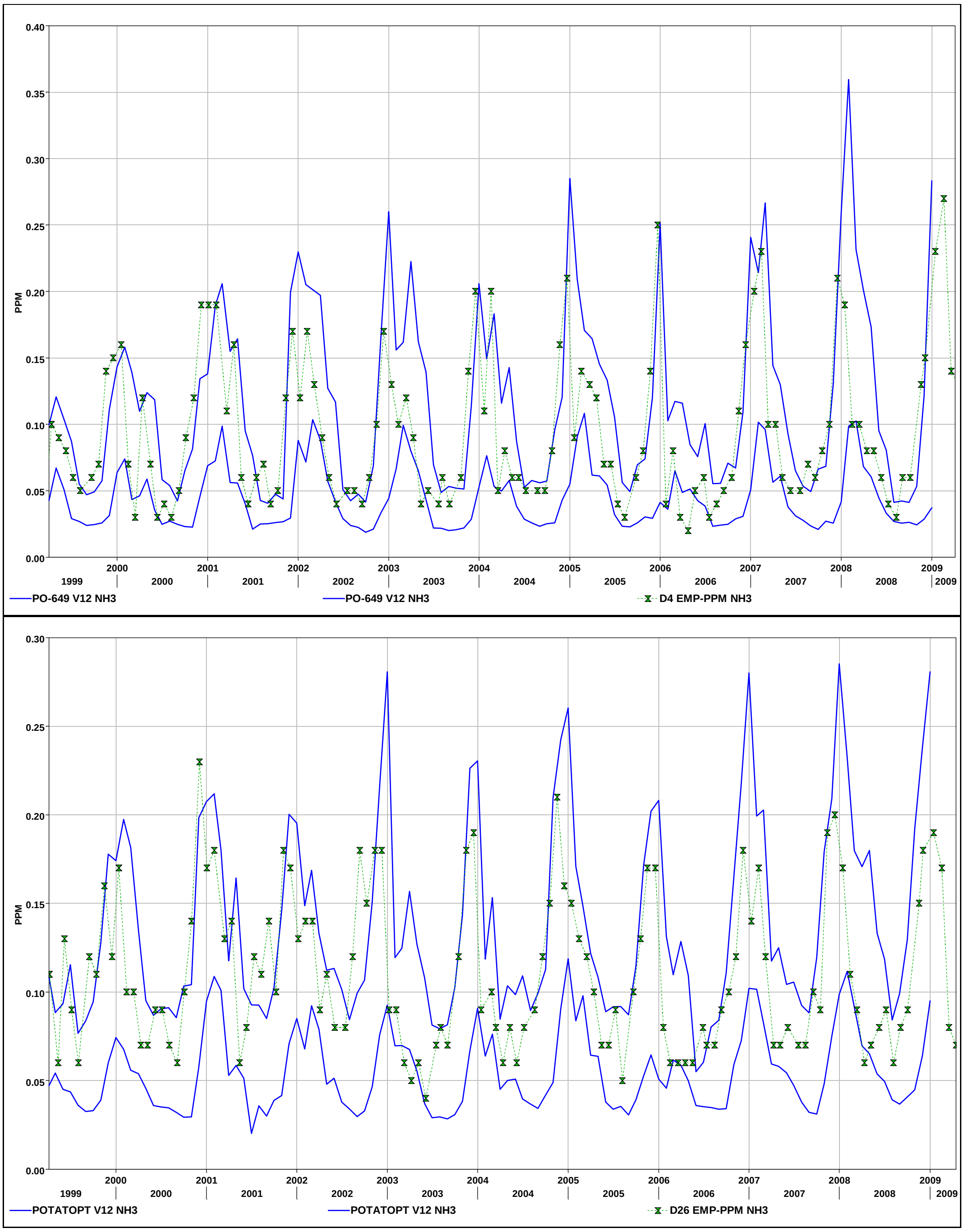


Figure 17-45 V12 model (calculated ammonia BC w/high flow constraint) at downstream locations, Point Sacramento (upper, PO-649) and at Potato Point (lower, D26).

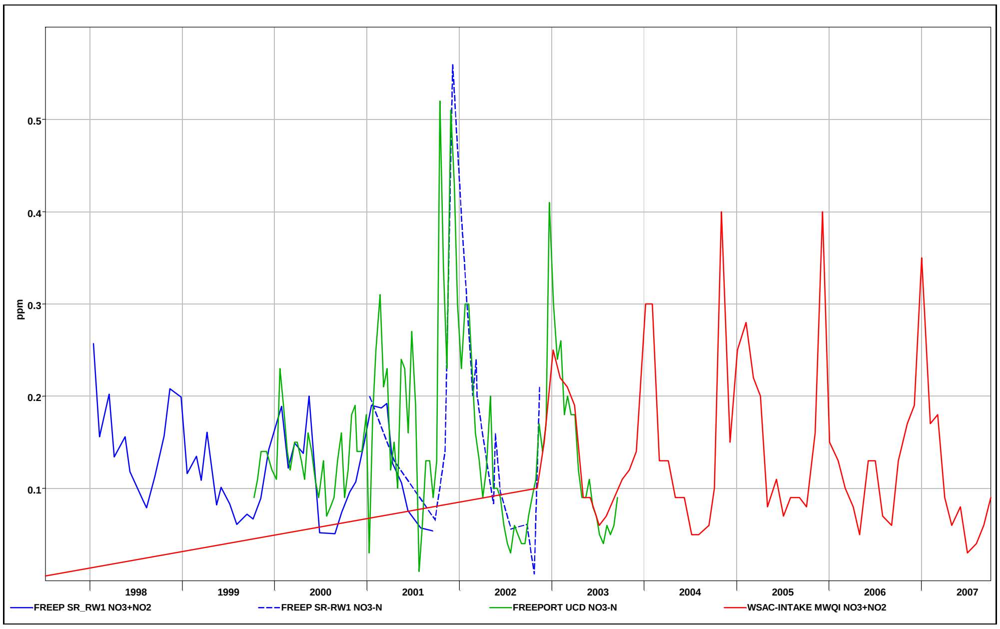


Figure 17-46 Four nitrate concentrations at or near Freeport – UC Davis data (green), BDAT data (red) and two Sac Regional receiving water datasets (blue, solid and dashed).

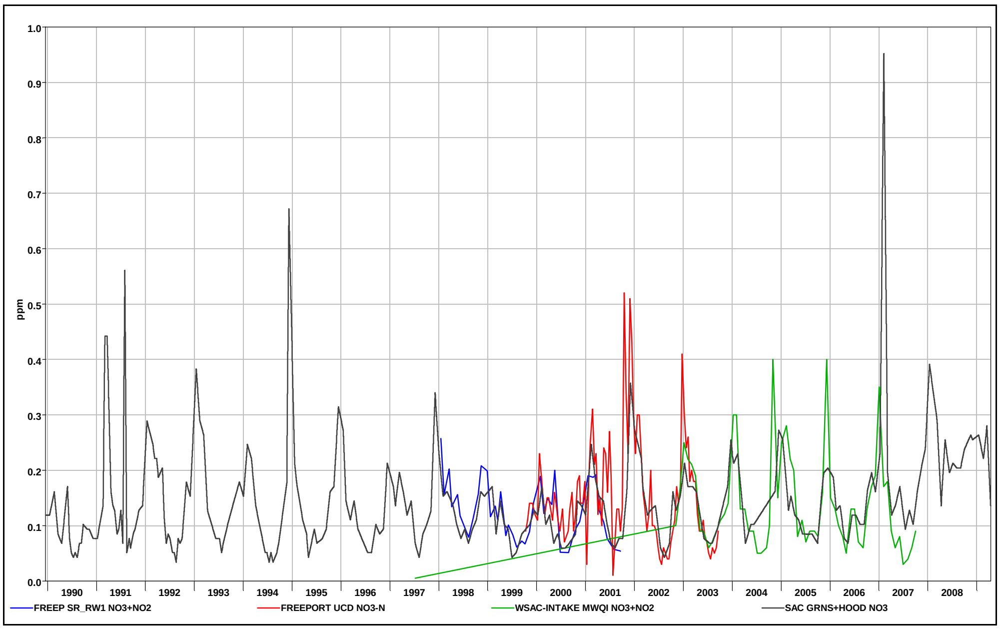


Figure 17-47 Nitrate data at or near Freeport *vs.* Sacramento R. BC: (black) BC set using EMP (Greens/Hood nitrate)*(0.825) vs. UC Davis data (green), Sac Regional receiving water data (blue) and MWQI monitoring data (green).

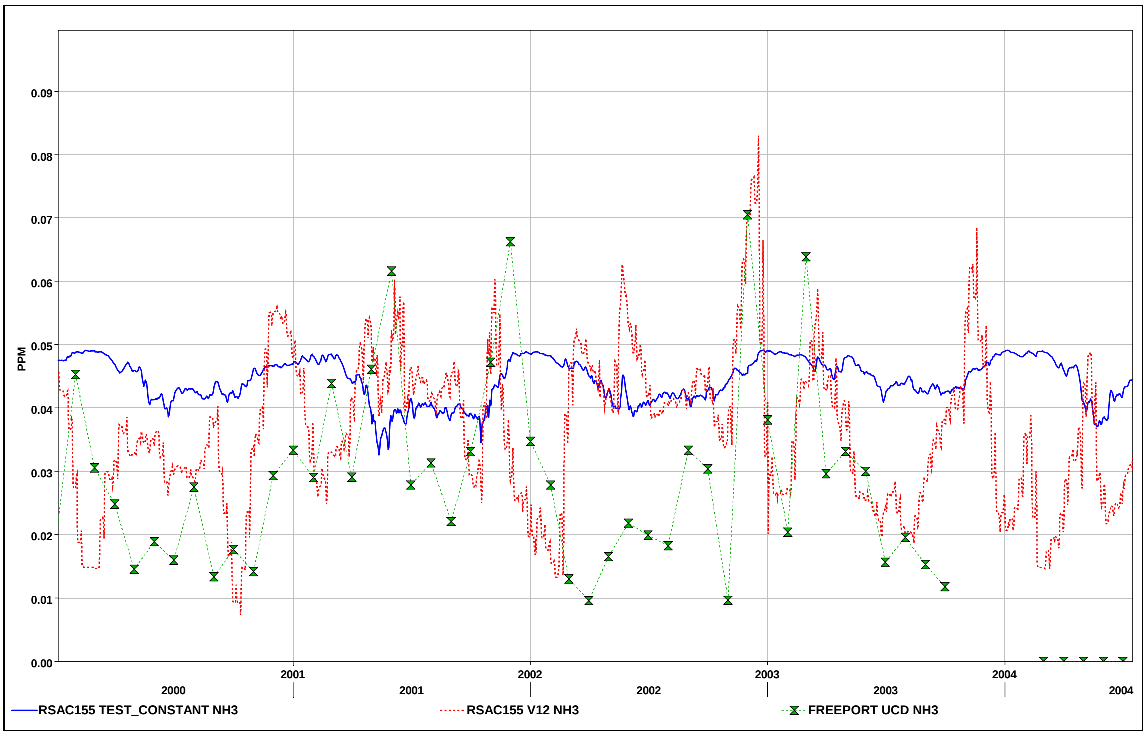


Figure 17-48 Modeled ammonia with constant concentration boundary (blue), “high flow” V12 boundary (red dash) vs. UC Davis ammonia data near Freeport (green symbols).

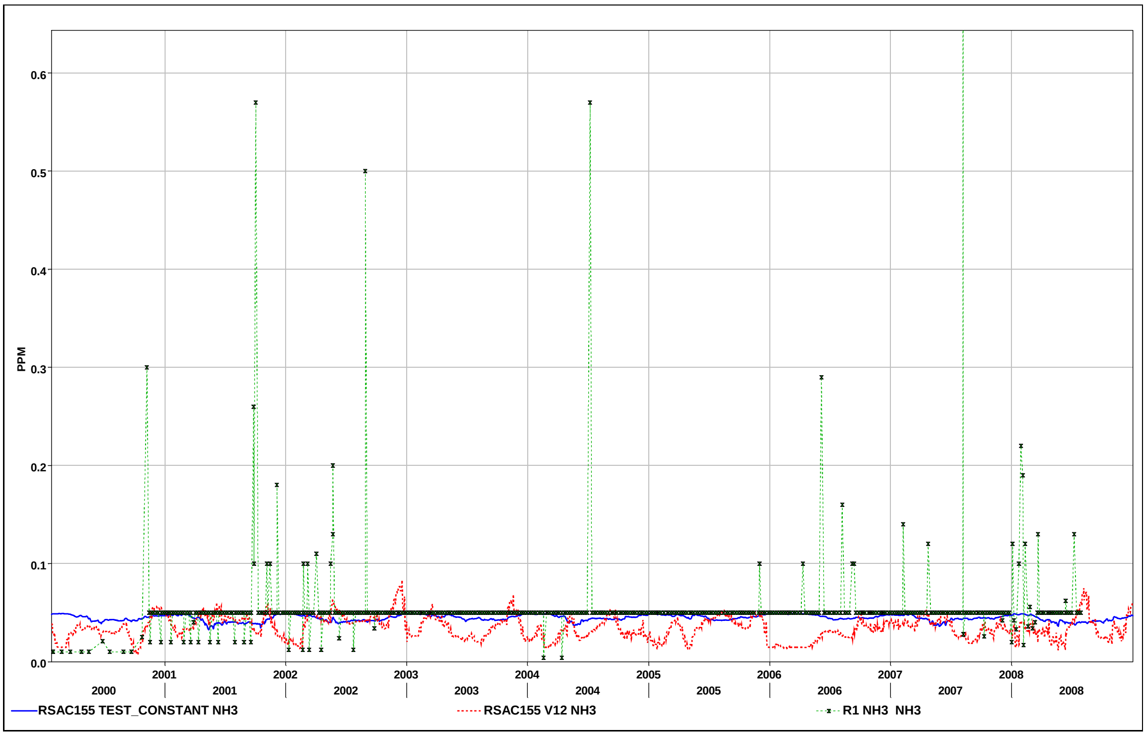


Figure 17-49 Modeled ammonia with the constant concentration boundary (blue) and. the "high flow" V12 boundary (red dash) vs. Sac Regional receiving water ammonia near Freeport (green symbols).

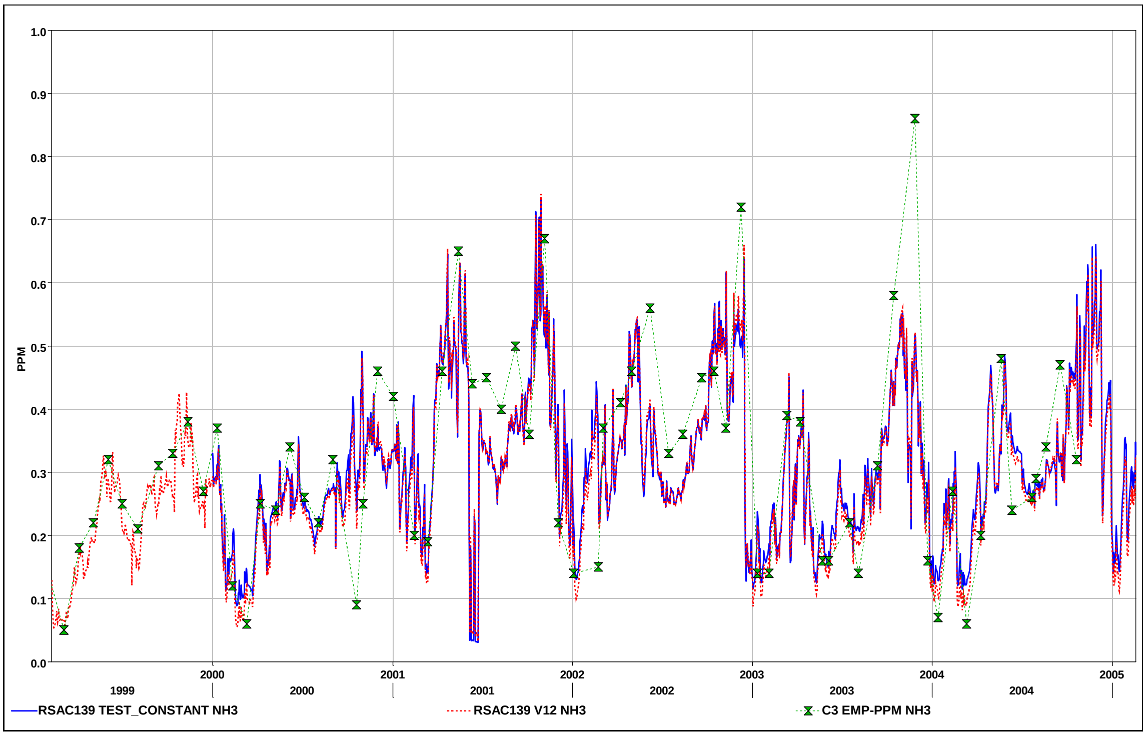


Figure 17-50 Modeled ammonia using the constant concentration boundary (blue) and the "high flow" V12 boundary (red dash) vs. EMP ammonia calibration data near Greens Landing (green symbols)

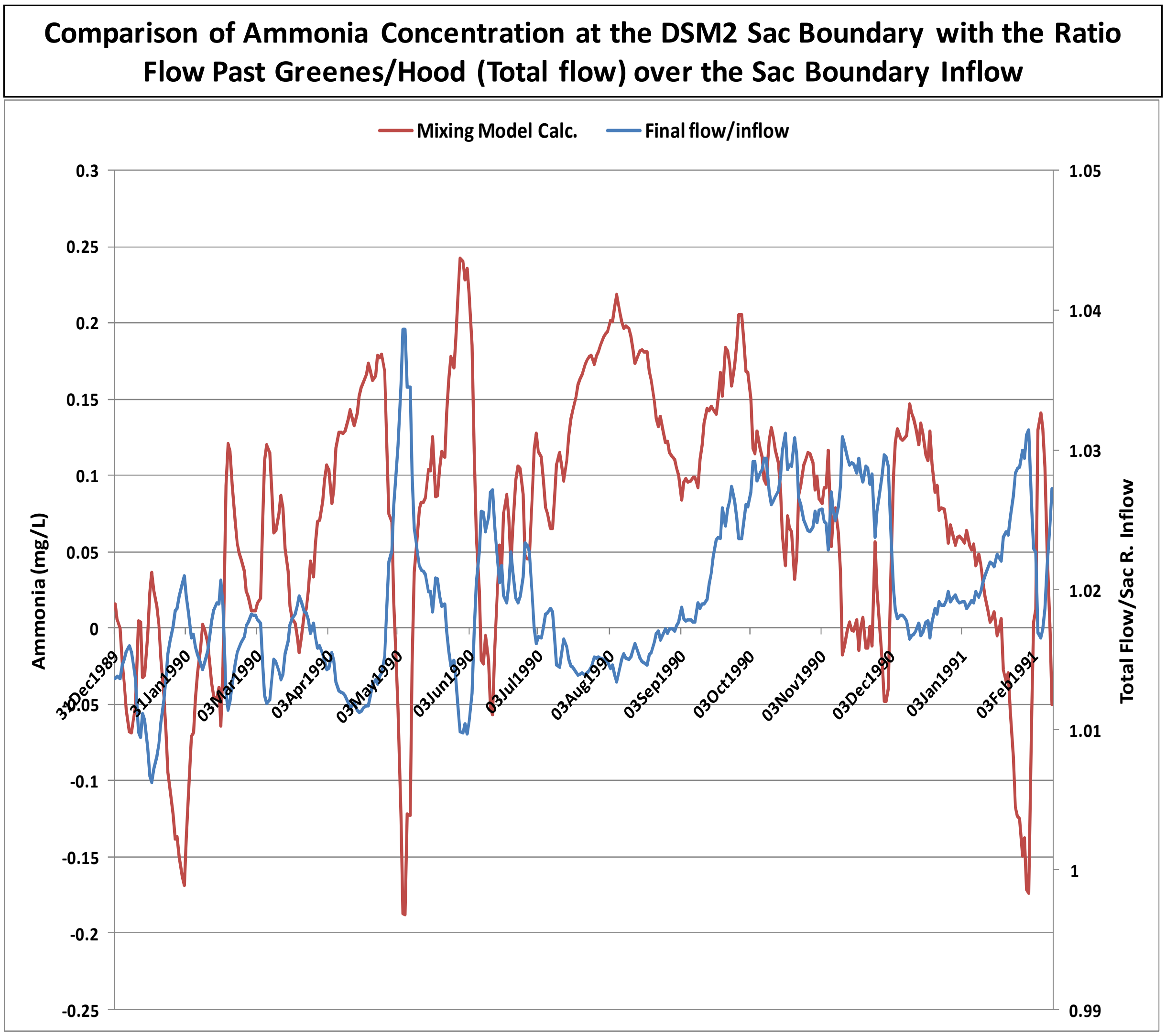


Figure 17-51 Mixing model calculation (red) compared with the flow ratio (Total flow)/Sac BC Inflow (blue)

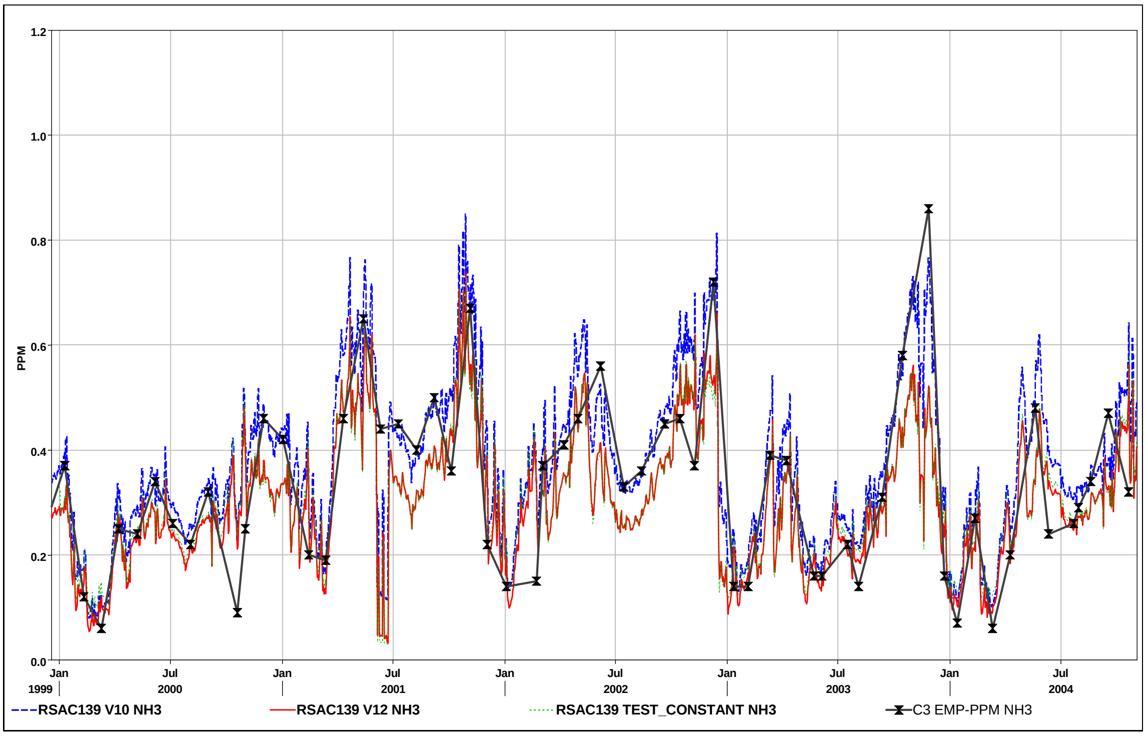


Figure 17-52 Modeled ammonia with three ammonia BC: constant concentration (green dash), "high flow" V12 (red dash), and previous calibrated model V10 with (Greens/Hood ammonia)*(0.4) (blue dash) vs. EMP data near Greens Landing (black symbols).

17.9 Calibration Statistics and Residual Analysis Methodology

17.9.1 Residual Analysis of the Water Temperature Model

Residuals are defined as the difference (data – model) between the measured data and the modeled result. As mentioned in Section 10.2, water temperature residuals were first calculated on an annual basis by Water Year Type at each location, and then the averages were calculated regionally for all locations in each of the three major regions. The Suisun and Yolo/Cache regions had only one data location, so averages were just calculated over the years present in a particular Water Year Type. Maximum and minimum values were determined by individual year and location within a region and Water Year type.

The following methodology and statistics (Moriasi et al., 2007) were used for the temperature data:

Mean Residual – The mean of the residual values gives an indication of the magnitude of model under-prediction (positive residuals) or over-prediction in a region. The optimal value is zero, which occurs in the unlikely situation that the model is a perfect fit for the data.

Standard Deviation of Residual – The standard deviation of the residual values gives an indication of the variability in model under-prediction and over-prediction in a region.

Residual Histogram – The histogram documents the shape of the residual distribution. Along with the mean and standard deviation, this gives a first-order view of the goodness of model fit. The ideal histogram would have an approximately normal shape centered at zero with a small spread. Histograms were prepared using annual calculations at each location.

MSE – The Mean Squared Error is a standard statistic that measures the quality of the prediction. The optimal value is zero:

$$MSE = \left[\frac{\sum_{i=1}^{n} \left(Y_i^{Obs} - Y_i^{Sim} \right)^2}{n} \right] \quad \text{(A3)}$$

RMSE – The Root Mean Squared Error is a standard statistic used to indicate the accuracy of the simulation. It is the square root of the MSE. The optimal value is zero.

NSE – The Nash-Sutcliffe Efficiency is a normalized statistic that measures the relative magnitude of the residual variance compared to the data variance. NSE indicates how well the measured vs. modeled data fit the 1:1 line (Moriasi et al., 2007). A value of 1 of optimal, values between 0 and 1 are acceptable, and negative values indicate that the data mean is a better predictor of the data than the model:

$$NSE = 1 - \left[\frac{\sum_{i=1}^{n} \left(Y_i^{Obs} - Y_i^{Sim} \right)^2}{\sum_{i=1}^{n} \left(Y_i^{Obs} - Y_i^{Mean} \right)^2} \right] \quad \text{(A4)}$$

PBIAS – Percent bias measures the average tendency of the simulated data to be larger or smaller than the measured data. A value of 0 of optimal – a positive value indicates underestimation bias and a negative value indicate overestimation bias:

$$PBIAS = \left[\frac{\sum_{i=1}^{n} \left(Y_i^{Obs} - Y_i^{Sim} \right) * 100}{\sum_{i=1}^{n} \left(Y_i^{Obs} \right)} \right] \quad \text{(A5)}$$

RSR – The RMSE-observation standard deviation ratio is a statistic that normalizes the RMSE using the standard deviation of the observations. Because it is normalized, it can be used to compare errors among various constituents (Moriasi et al., 2007). A value of 0 is optimal:

$$RSR = \frac{\left[\sqrt{\sum_{i=1}^{n} \left(Y_i^{Obs} - Y_i^{Sim} \right)^2} \right]}{\left[\sqrt{\sum_{i=1}^{n} \left(Y_i^{Obs} - Y_i^{Mean} \right)^2} \right]} \quad \text{(A6)}$$

Table 17-9 Comparison of Calibration and Validation statistics for Critically Dry Water Years.

Calibration Critical	Mean_Residual	StDev_Residual	NSE_stat	MSE_stat	RMSE_stat	PBIAS_stat	RSR_stat	Mean_data	StDev_data
SJR									
Average	0.64	1.16	0.95	2.54	1.46	3.90	0.28	16.41	5.09
Max	0.93	1.21	0.98	2.03	1.42	5.28	0.28	17.70	5.70
Min	-0.18	0.94	0.94	0.89	0.02	-1.04	0.00	16.21	4.75
SAC									
Average	0.18	1.02	0.96	1.31	1.13	0.98	0.22	16.23	5.14
Max	0.93	1.21	0.98	2.03	1.42	5.28	0.28	17.70	5.70
Min	-0.64	0.78	0.94	0.76	0.87	-4.17	0.16	15.41	4.77
S Delta									
Average	1.51	1.38	0.94	4.47	2.08	8.57	0.36	17.62	5.73
Max	2.11	2.11	2.11	3.90	2.11	7.18	2.11	17.72	6.12
Min	0.81	1.20	0.94	2.49	0.14	0.00	0.00	17.38	5.62
Cache Sl									
Value	-0.78	1.54	0.91	2.96	1.72	-4.79	0.33	16.28	5.16
Suisun Marsh									
Value	-0.02	1.43	0.91	2.04	1.43	-0.11	0.29	17.06	4.88

Validation Critical	Mean_Residual	StDev_Residual	NSE_stat	MSE_stat	RMSE_stat	PBIAS_stat	RSR_stat	Mean_data	StDev_data
SJR									
Average	0.51	1.24	0.95	2.63	1.46	2.80	0.25	16.01	5.62
Max	1.60	1.94	0.98	6.29	2.51	9.12	0.37	18.45	6.70
Min	-0.27	0.63	0.92	0.41	0.64	-1.69	0.16	11.22	3.56
SAC									
Average	0.10	0.74	0.98	0.65	0.77	0.49	0.16	15.89	5.01
Max	0.46	1.10	0.99	1.22	1.10	2.48	0.22	18.56	5.88
Min	-0.19	0.44	0.95	0.22	0.47	-1.46	0.10	11.99	3.76
S Delta									
Average	0.92	1.24	0.93	3.37	1.79	3.31	0.37	15.62	5.41
Max	1.97	1.58	0.97	6.37	2.52	11.09	0.67	17.91	6.38
Min	-1.10	0.80	0.84	1.82	1.35	-17.68	0.25	6.21	2.01
Cache Sl									
Value									
Suisun Marsh									
Value									

Table 17-10 Comparison of Calibration and Validation statistics for Dry Water Years.

Calibration Dry	Mean_Residual	StDev_Residual	NSE_stat	MSE_stat	RMSE_stat	PBIAS_stat	RSR_stat	Mean_data	StDev_data
SJR									
Average	0.32	1.04	0.96	1.58	1.17	1.84	0.22	16.67	5.17
Max	1.43	1.45	0.97	4.13	2.03	8.10	0.34	17.64	5.97
Min	-0.24	0.80	0.94	0.64	0.80	-1.45	0.16	16.33	4.62
SAC									
Average	-0.01	0.83	0.97	0.78	0.87	-0.07	0.17	16.18	5.02
Max	0.42	1.07	0.98	1.17	1.08	2.58	0.22	16.37	5.41
Min	-0.41	0.66	0.96	0.54	0.74	-2.61	0.14	15.84	4.63
S Delta									
Average	1.07	1.31	0.95	2.89	1.69	6.14	0.29	17.48	5.82
Max	1.28	1.34	0.95	3.42	1.85	7.27	0.32	17.56	5.83
Min	0.87	1.27	0.95	2.37	1.54	5.00	0.26	17.39	5.81
Cache Sl									
Value	-0.55	1.22	0.95	1.80	1.34	-3.46	0.25	15.98	5.42
Suisun Marsh									
Value	0.15	1.04	0.92	1.10	1.05	1.14	0.28	13.26	3.78

Validation Dry	Mean_Residual	StDev_Residual	NSE_stat	MSE_stat	RMSE_stat	PBIAS_stat	RSR_stat	Mean_data	StDev_data
SJR									
Average	0.53	1.13	0.95	1.91	1.34	2.97	0.26	17.22	5.11
Max	1.25	1.59	0.98	3.30	1.82	6.90	0.31	18.11	5.94
Min	-0.24	0.79	0.92	0.63	0.79	-1.45	0.15	16.45	4.28
SAC									
Average	-0.11	0.85	0.89	1.23	1.03	-0.60	0.31	15.80	4.55
Max	1.19	1.30	0.99	3.84	1.96	9.45	1.59	17.68	5.54
Min	-1.77	0.46	-0.05	0.24	0.49	-12.79	0.09	9.29	0.71
S Delta									
Average	0.61	1.19	0.95	2.02	1.40	3.42	0.26	17.61	5.48
Max	1.12	1.27	0.96	2.82	1.68	6.32	0.30	18.01	5.85
Min	-0.06	1.09	0.94	1.35	1.16	-0.33	0.21	16.74	5.27
Cache Sl									
Value	-0.59	1.38	0.91	2.33	1.52	-3.58	0.31	16.54	4.87
Suisun Marsh	-0.14	1.28	0.92	1.70	1.29	-0.86	0.28	16.37	4.59
Value									

Table 17-11 Comparison of Calibration and validation statistics for Above Normal Water Years.

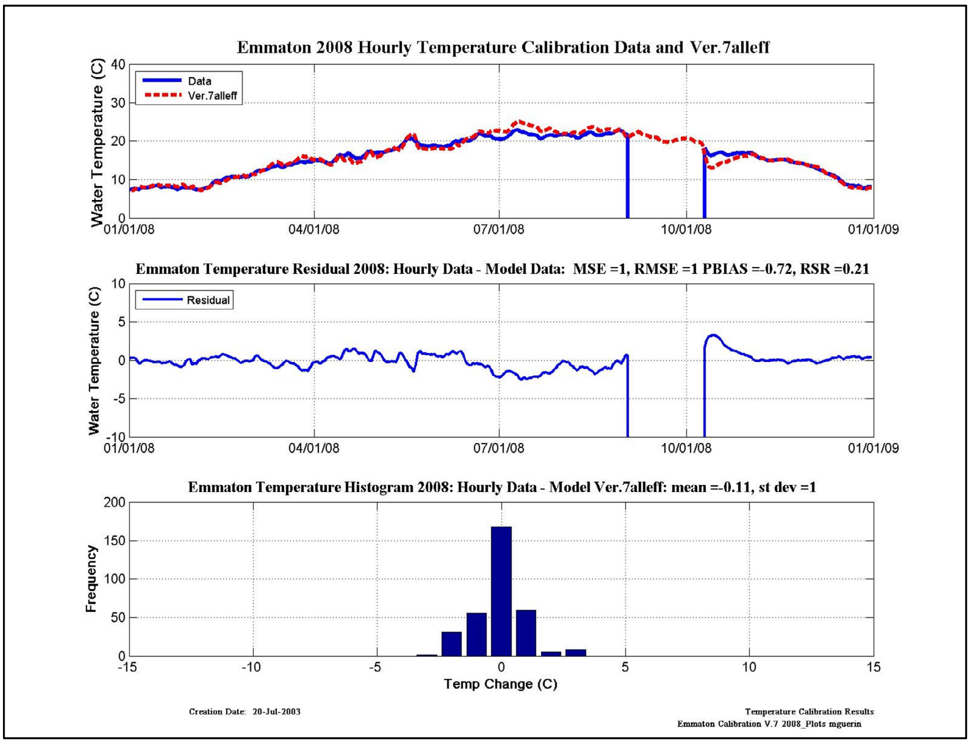
Calibration AN	Mean_Residual	StDev_Residual	NSE_stat	MSE_stat	RMSE_stat	PBIAS_stat	RSR_stat	Mean_data	StDev_data
SJR									
Average	0.39	0.96	0.96	1.30	1.10	2.23	0.22	17.12	4.95
Max	1.03	1.43	0.98	2.32	1.52	5.90	0.29	18.84	5.58
Min	-0.17	0.77	0.96	0.64	0.01	-1.03	0.00	16.52	4.43
SAC									
Average	0.04	0.72	0.98	0.65	0.64	0.10	0.14	16.20	4.40
Max	0.48	0.97	1.00	1.13	1.06	2.91	0.25	16.36	4.75
Min	-0.43	0.38	0.95	0.15	0.06	-2.68	0.00	16.02	4.17
S Delta									
Average	0.56	1.19	0.95	1.84	1.34	3.25	0.26	17.20	5.20
Max	1.03	1.43	0.96	2.32	1.52	5.90	0.29	17.60	5.58
Min	0.34	0.97	0.94	1.15	0.08	0.00	0.00	17.00	4.91
Cache Sl									
Value	-0.33	1.51	0.89	2.38	1.54	-1.95	0.33	17.00	4.63
Suisun Marsh									
Value	-0.14	1.18	0.93	1.40	1.18	-0.85	0.26	16.72	4.51

Validation AN	Mean_Residual	StDev_Residual	NSE_stat	MSE_stat	RMSE_stat	PBIAS_stat	RSR_stat	Mean_data	StDev_data
SJR									
Average	0.11	1.04	0.94	1.44	1.15	0.52	0.26	16.81	4.62
Max	1.12	1.72	0.97	3.27	1.81	6.19	0.49	18.15	5.68
Min	-0.57	0.78	0.78	0.64	0.80	-3.61	0.17	15.82	3.68
SAC									
Average	-0.38	0.83	0.96	1.72	1.09	-2.53	0.24	16.18	4.58
Max	0.62	1.50	0.99	9.23	3.04	3.61	0.74	17.47	5.17
Min	-2.91	0.35	0.90	0.12	0.35	-18.92	0.07	14.56	4.08
S Delta									
Average	0.65	1.02	0.96	1.65	1.26	3.56	0.24	17.96	5.32
Max	1.30	1.13	0.97	2.70	1.64	6.98	0.30	18.59	5.44
Min	0.11	0.92	0.95	0.85	0.92	0.67	0.17	17.19	5.12
Cache Sl									
Value	-0.54	1.28	0.94	1.94	1.39	-3.26	0.28	16.60	5.03
Suisun Marsh	-0.28	1.16	0.93	1.44	1.20	-1.73	0.26	16.49	4.53
Value									

Table 17-12 Comparison of Calibration and validation statistics for Wet Water Years.

Calibration Wet	Mean_Residual	StDev_Residual	NSE_stat	MSE_stat	RMSE_stat	PBIAS_stat	RSR_stat	Mean_data	StDev_data
SJR									
Average	0.15	0.63	0.98	0.46	0.68	0.89	0.14	16.32	4.89
Max	0.35	0.73	0.99	0.56	0.75	2.17	0.16	16.48	4.97
Min	-0.08	0.49	0.98	0.36	0.60	-0.50	0.12	16.21	4.75
SAC									
Average	0.12	0.71	0.84	0.53	0.77	0.43	2.67	14.01	4.72
Max	0.62	1.00	1.00	0.89	1.03	3.94	15.24	16.01	4.90
Min	-0.30	0.34	0.13	0.11	0.34	-1.93	0.07	4.86	4.59
S Delta									
Average	0.40	0.90	0.97	1.03	0.99	2.39	0.18	16.68	5.46
Max	0.41	1.16	0.99	1.48	1.22	2.50	0.22	16.90	5.65
Min	0.39	0.64	0.96	0.57	0.76	2.29	0.14	16.46	5.26
Cache Sl									
Value	-0.25	1.17	0.95	1.43	1.20	-1.52	0.24	16.48	5.07
Suisun Marsh									
Value	-0.27	1.06	0.95	1.20	1.10	-1.68	0.23	16.36	4.80

Validation Wet	Mean_Residual	StDev_Residual	NSE_stat	MSE_stat	RMSE_stat	PBIAS_stat	RSR_stat	Mean_data	StDev_data
SJR									
Average	0.61	0.46	0.96	1.55	1.07	5.38	0.77	12.51	2.26
Max	1.94	0.83	0.99	3.77	1.94	17.35	1.84	17.16	4.19
Min	-0.10	0.13	0.92	0.19	0.43	-1.09	0.20	9.20	1.05
SAC									
Average	-0.32	0.98	0.82	1.38	0.95	-2.48	2.46	14.36	4.26
Max	0.37	1.69	0.99	4.94	2.22	0.44	15.62	17.92	4.89
Min	-1.45	0.51	0.14	0.26	-0.04	-10.18	0.10	4.97	3.45
S Delta									
Average	0.92	1.19	0.96	2.41	1.51	5.32	0.26	17.16	5.69
Max	1.27	1.38	0.97	3.51	1.87	7.13	0.32	17.80	5.89
Min	0.58	0.99	0.95	1.32	1.15	3.51	0.21	16.51	5.49
Cache Sl									
Value	-0.27	1.34	0.91	1.86	1.36	-1.62	0.31	16.99	4.37
Suisun Marsh	-0.20	1.28	0.93	1.67	1.29	-1.27	0.27	15.64	4.70
Value									



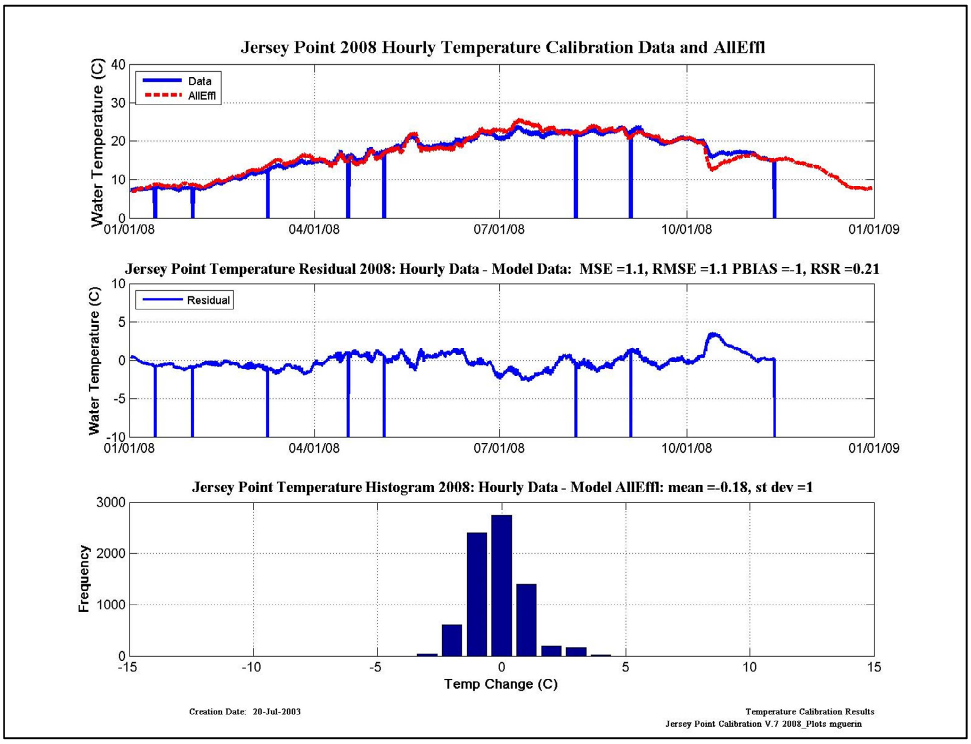
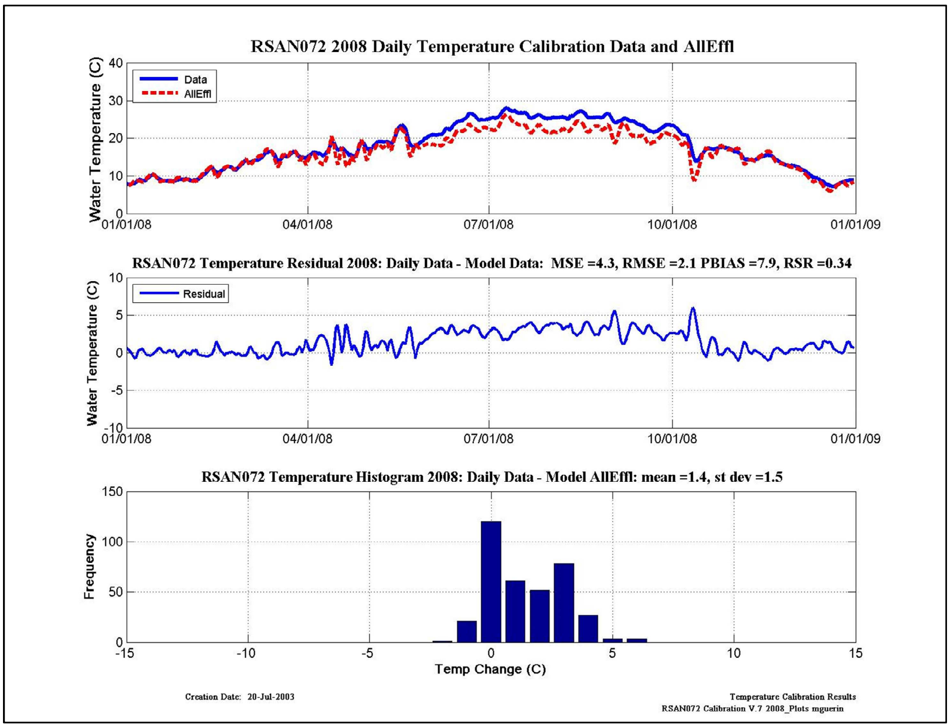


Figure 17-53 Calibration plots in the Critically Dry WY 2008 at Emmaton and Jersey Point.



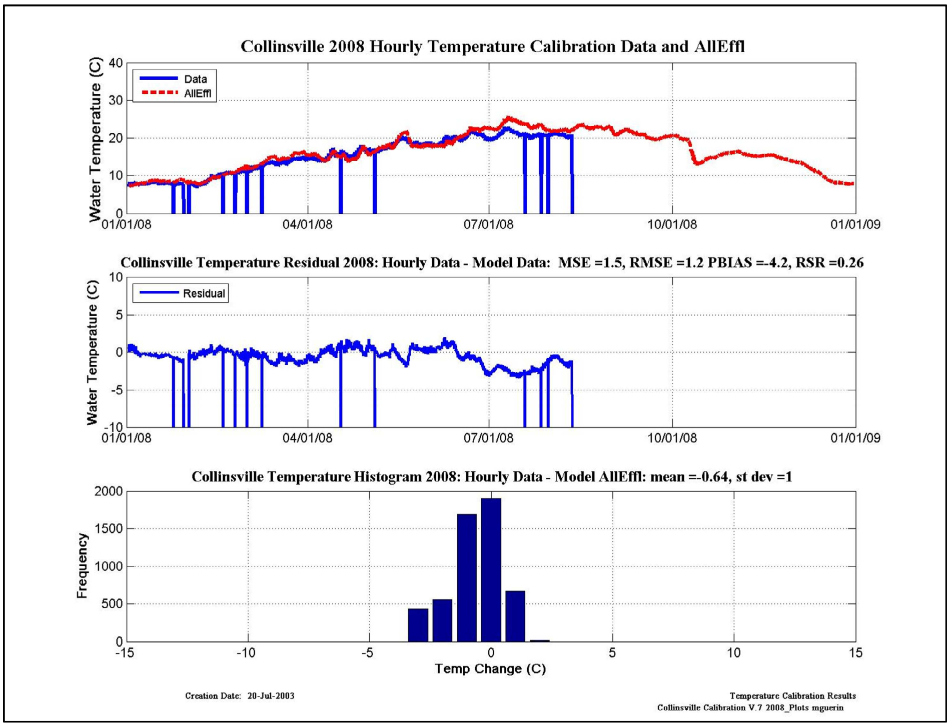


Figure 17-54 Calibration plots in the Critically Dry WY 2008 at RSAN072 on the San Joaquin and at Collinsville.

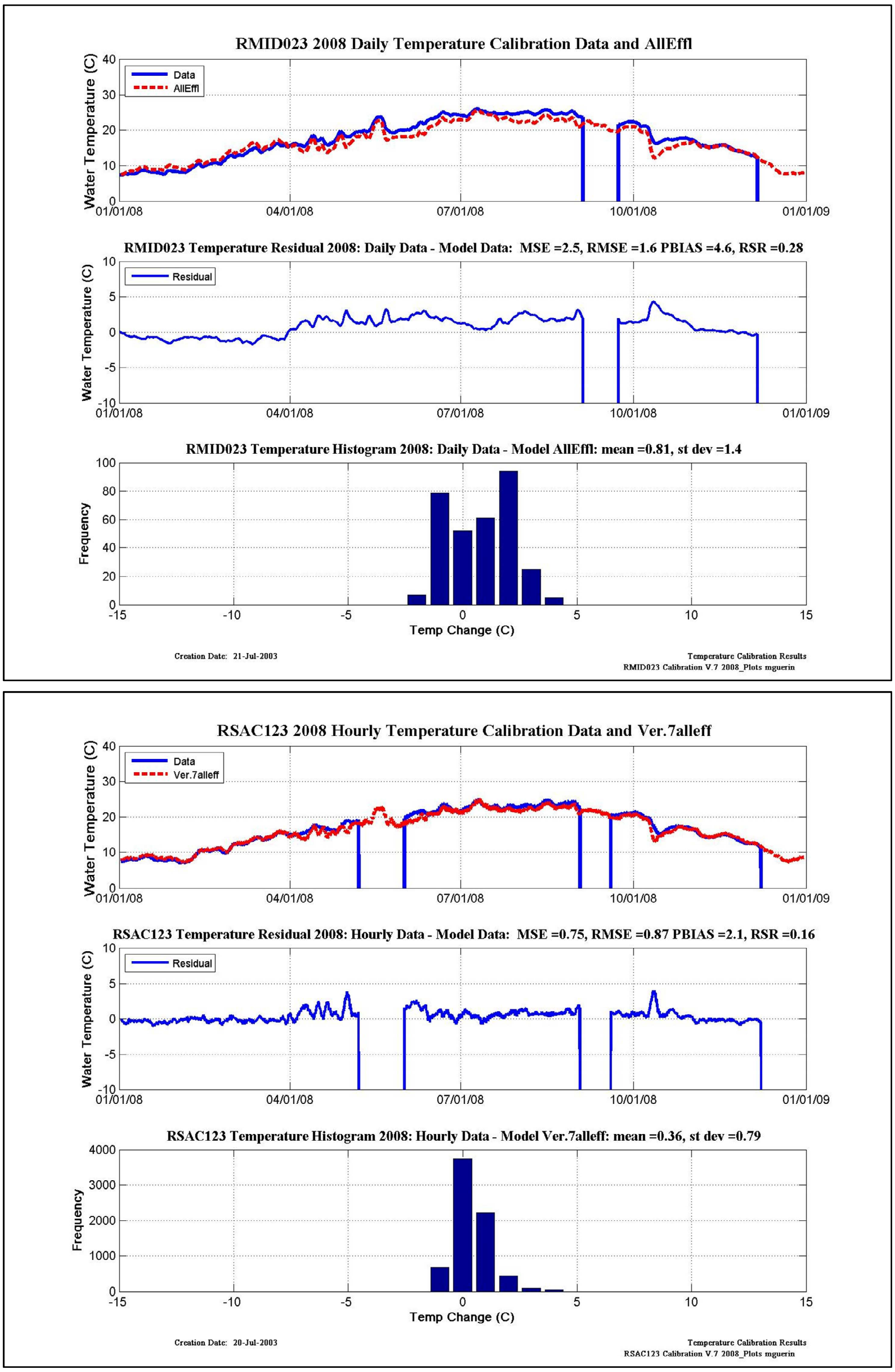
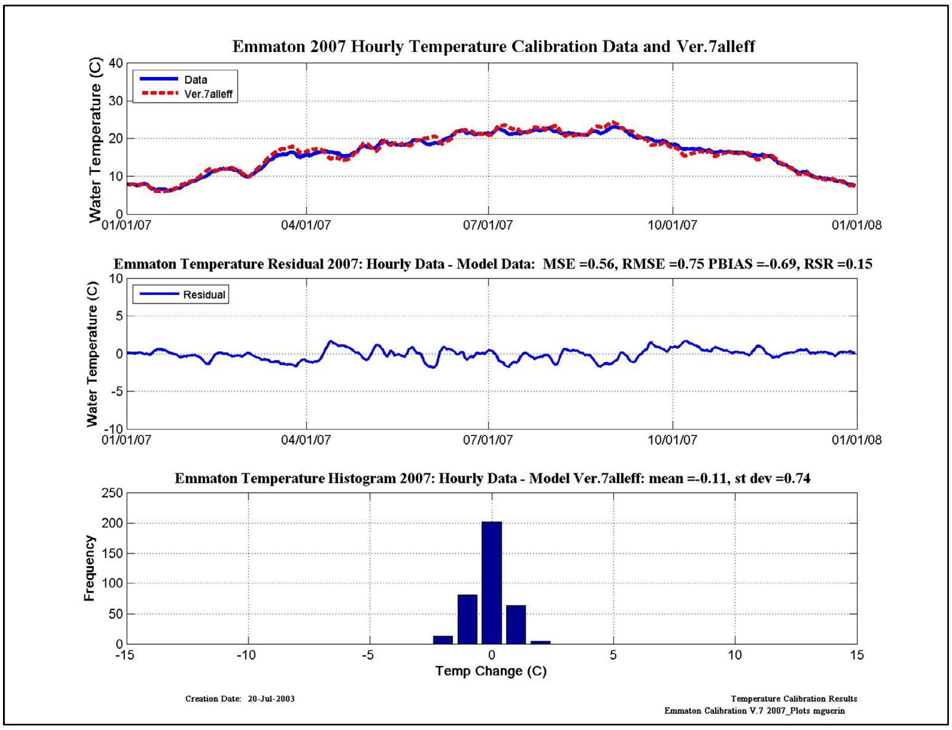


Figure 17-55 Calibration plots in the Critically Dry WY 2008 at RMID023 on Middle R. in the South Delta and at RSAC123 on the upper Sacramento R.



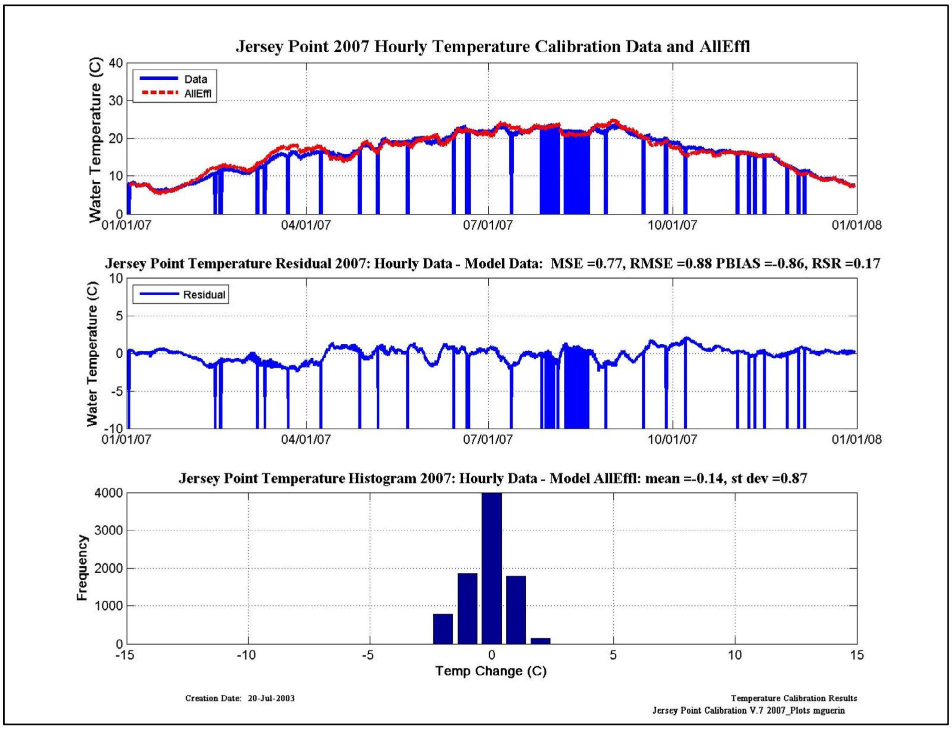


Figure 17-56 Calibration plots in the Dry WY 2007 at Emmaton and Jersey Point.

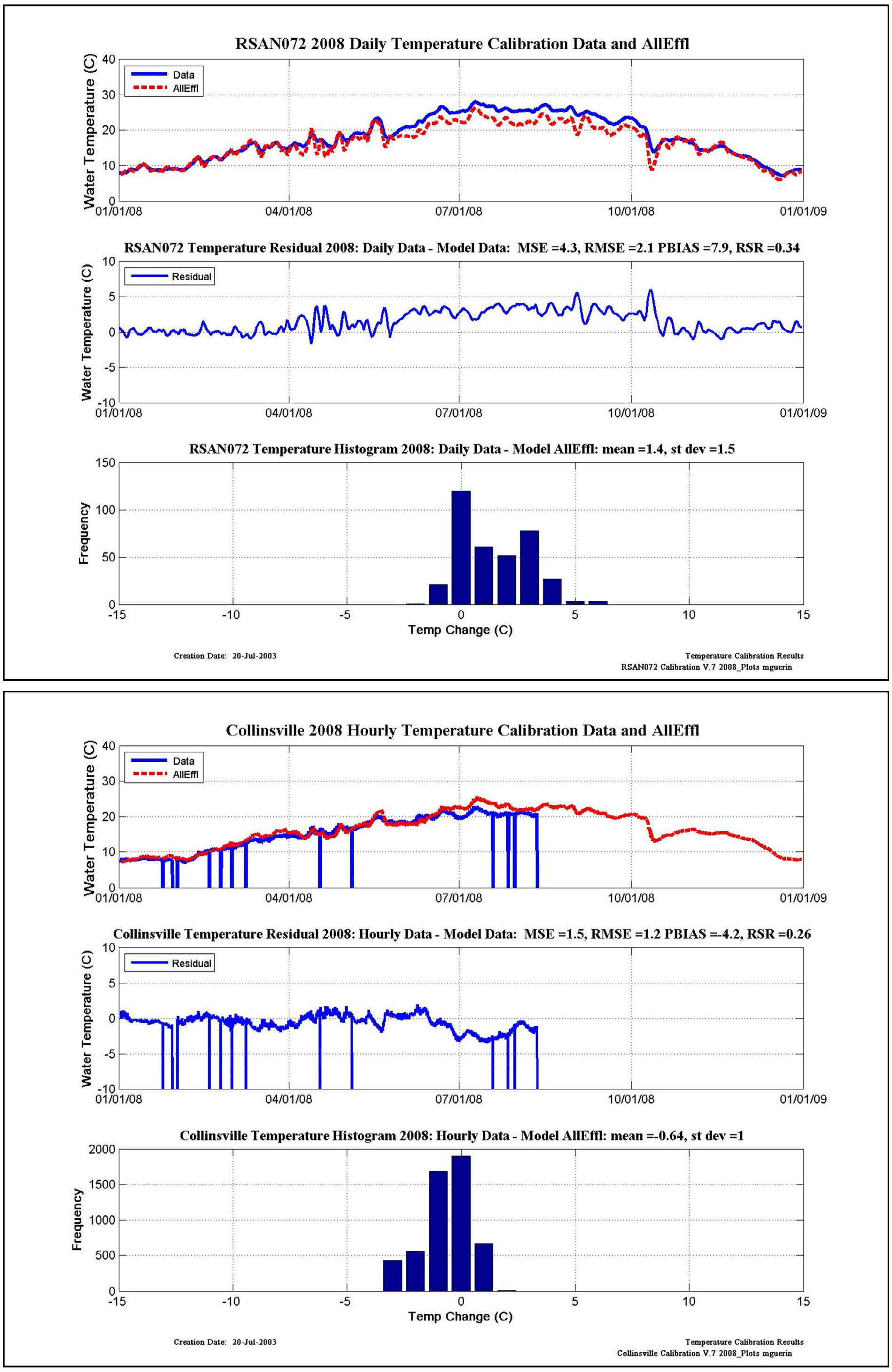


Figure 17-57 Calibration plots in the Dry WY 2007 at RSAN072 on the San Joaquin and at Collinsville.

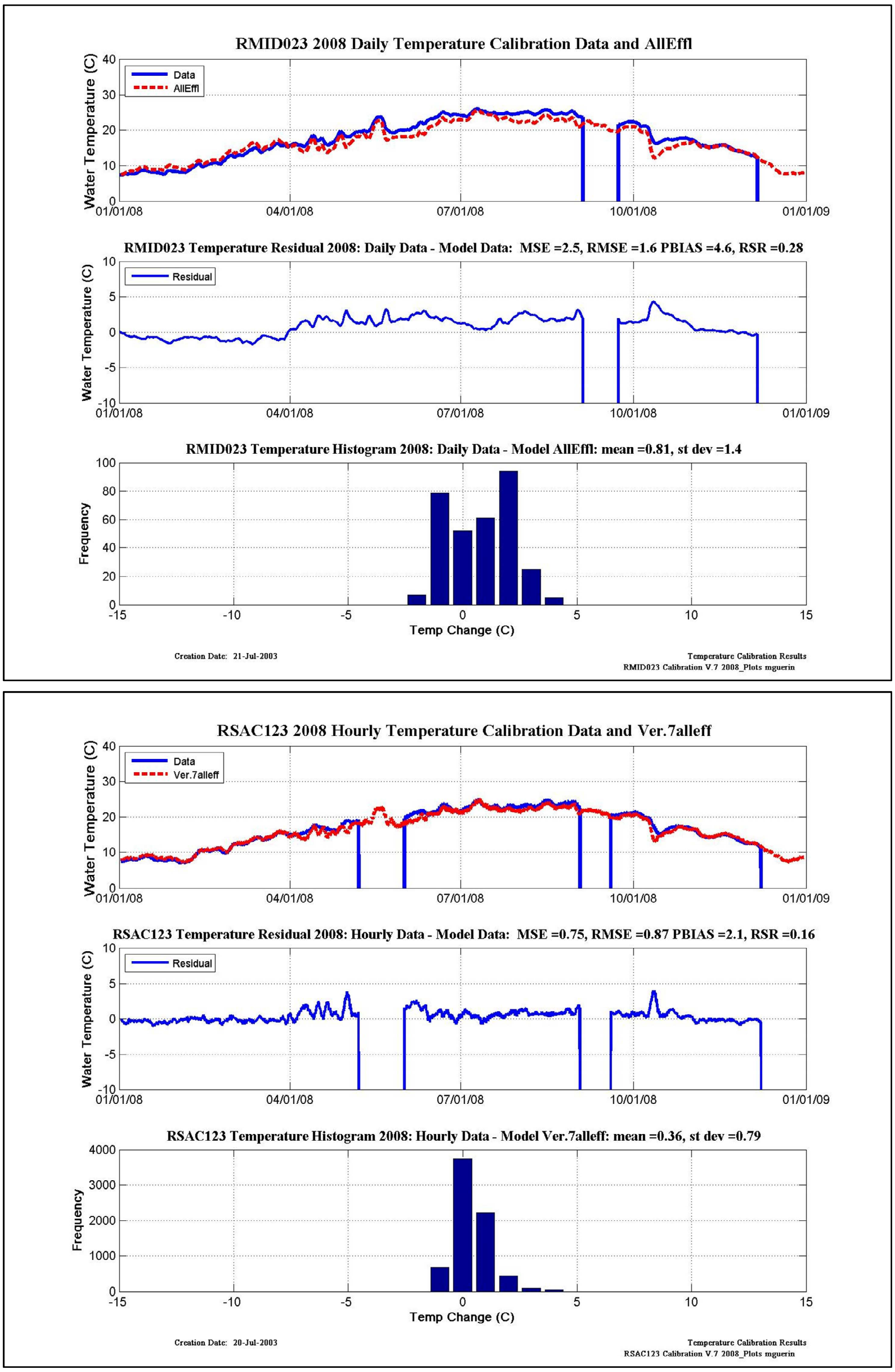
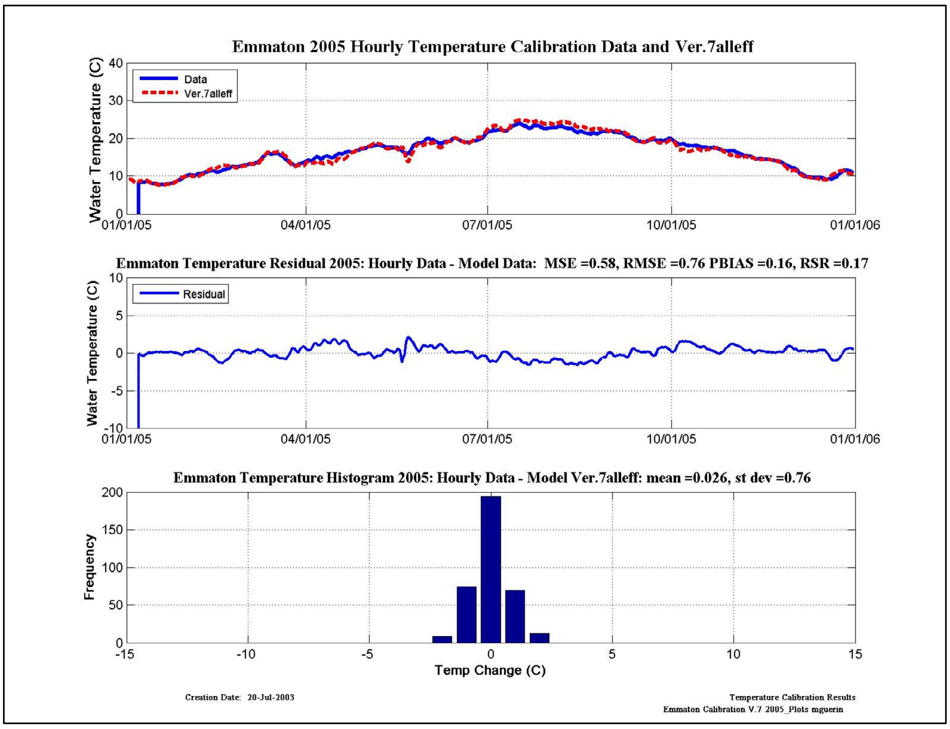


Figure 17-58 Calibration plots in the Dry WY 2007 at RMID023 on Middle R. in the South Delta and at RSAC123 on the upper Sacramento R.



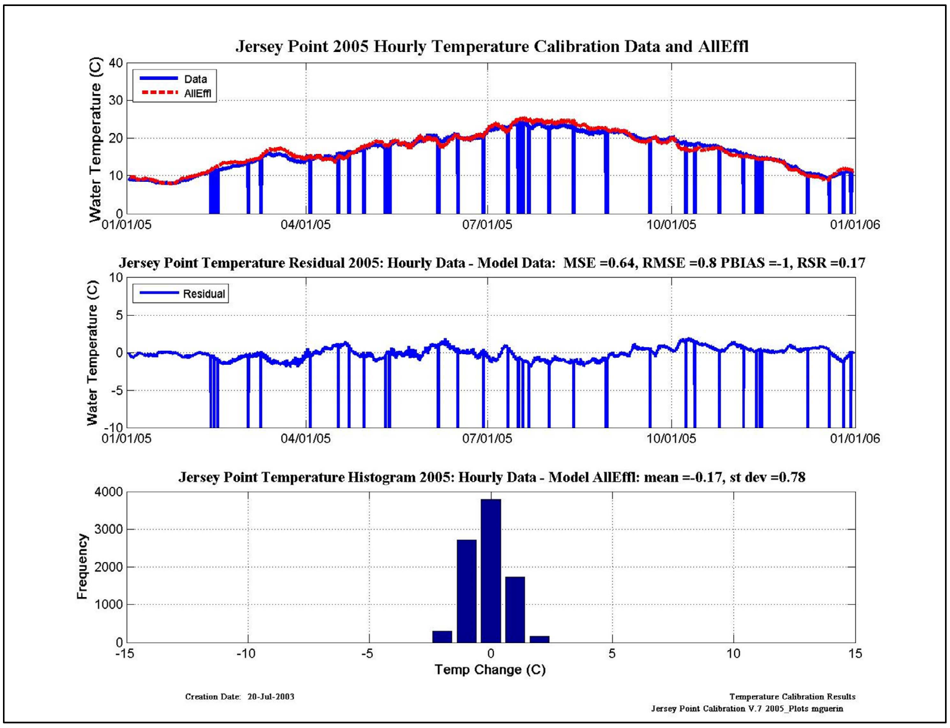
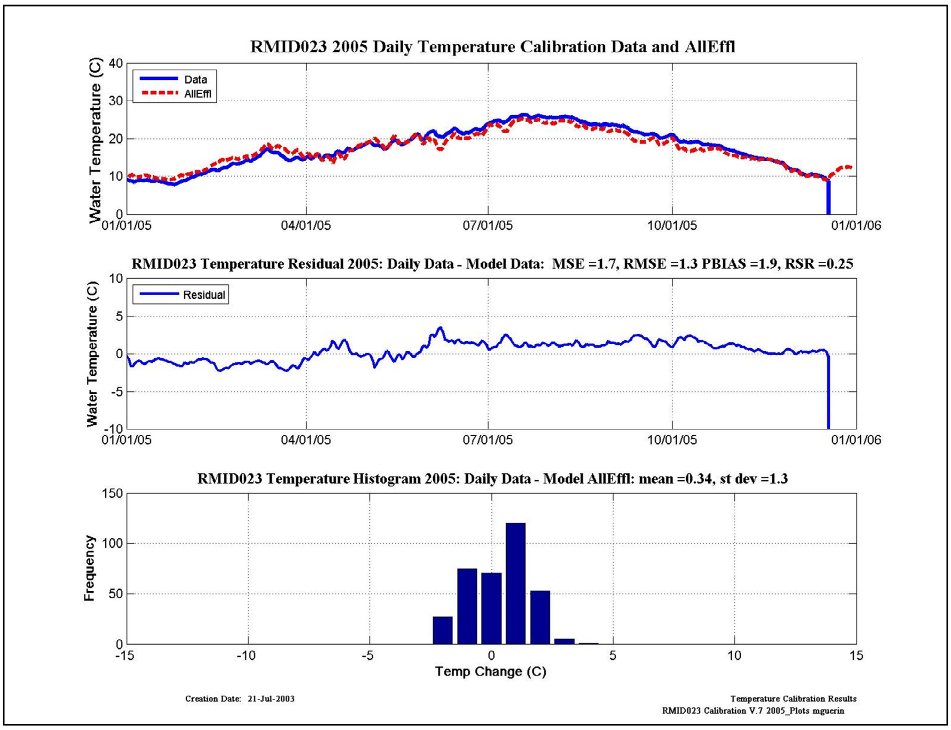


Figure 17-59 Calibration plots in the Abv. Normal WY 2005 at Emmaton and Jersey Point.



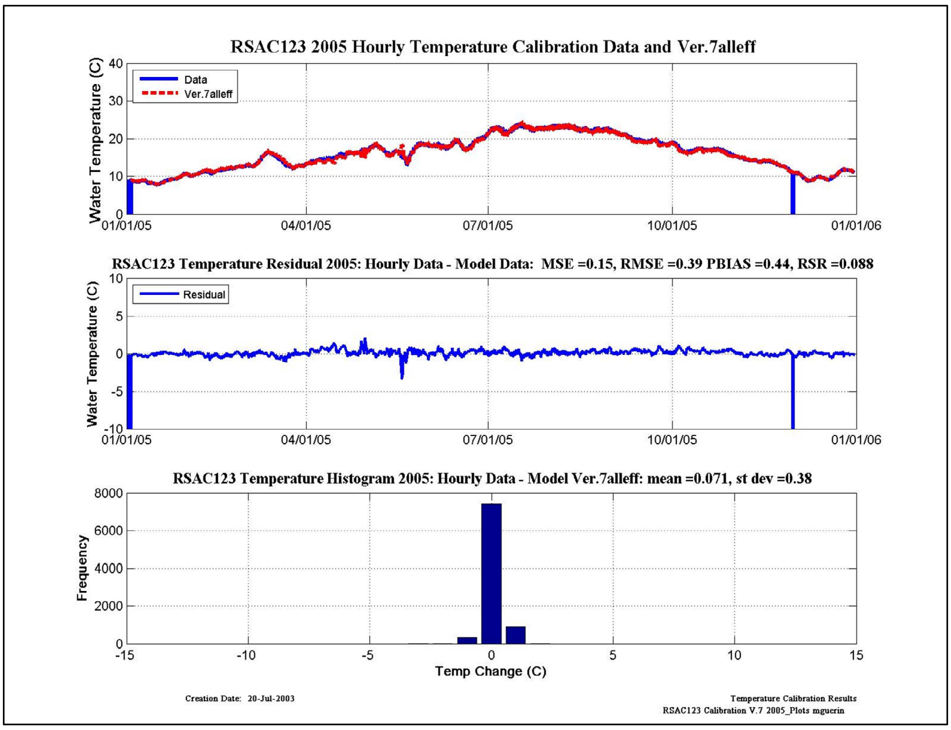
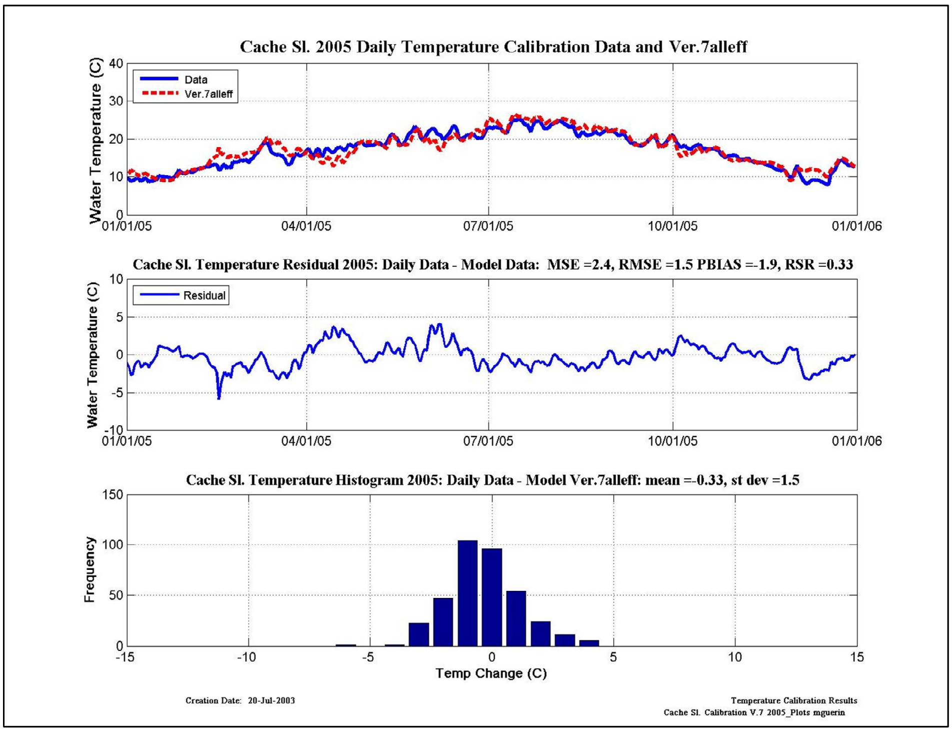


Figure 17-60 Calibration plots in the Abv Normal WY 2005 at RMID023 on Middle R. in the South Delta and at RSAC123 on the upper Sacramento R.



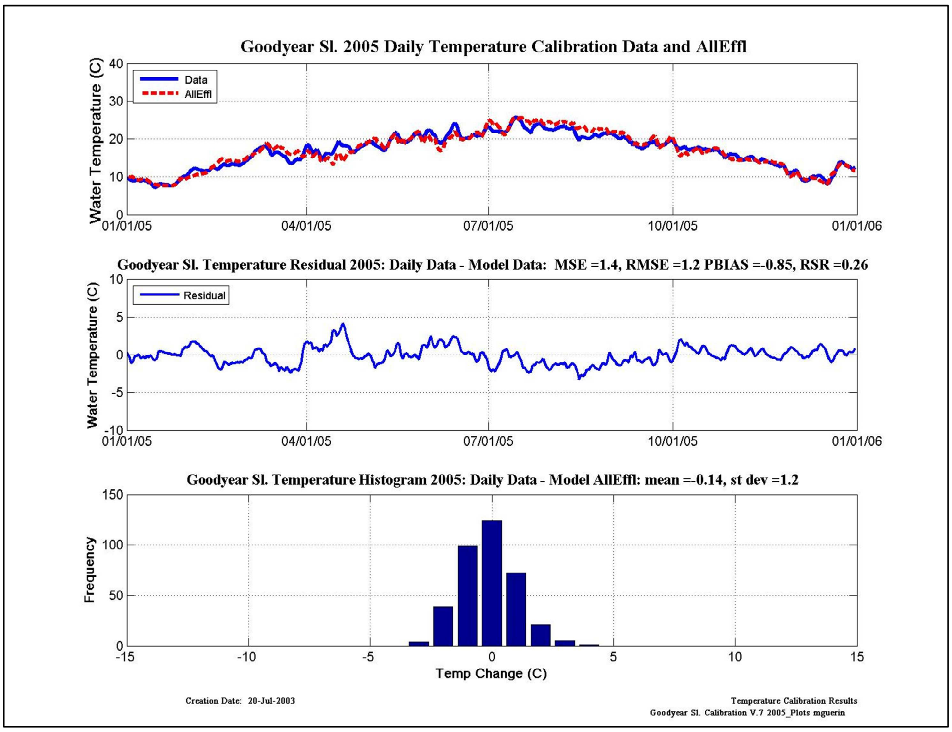


Figure 17-61 Calibration plots in the Abv Normal WY 2005 at Cache Sl. and at Goodyear Sl.

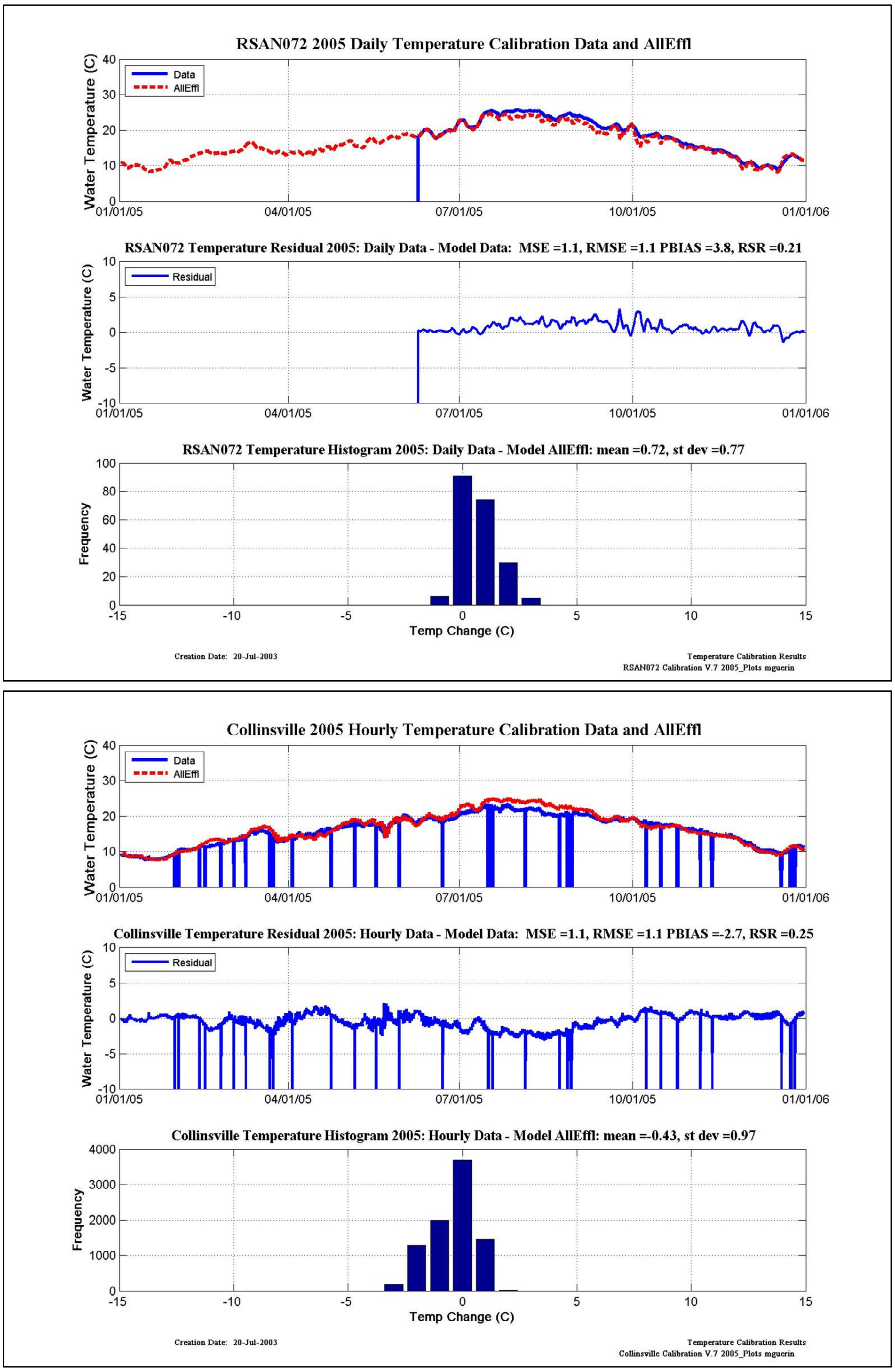
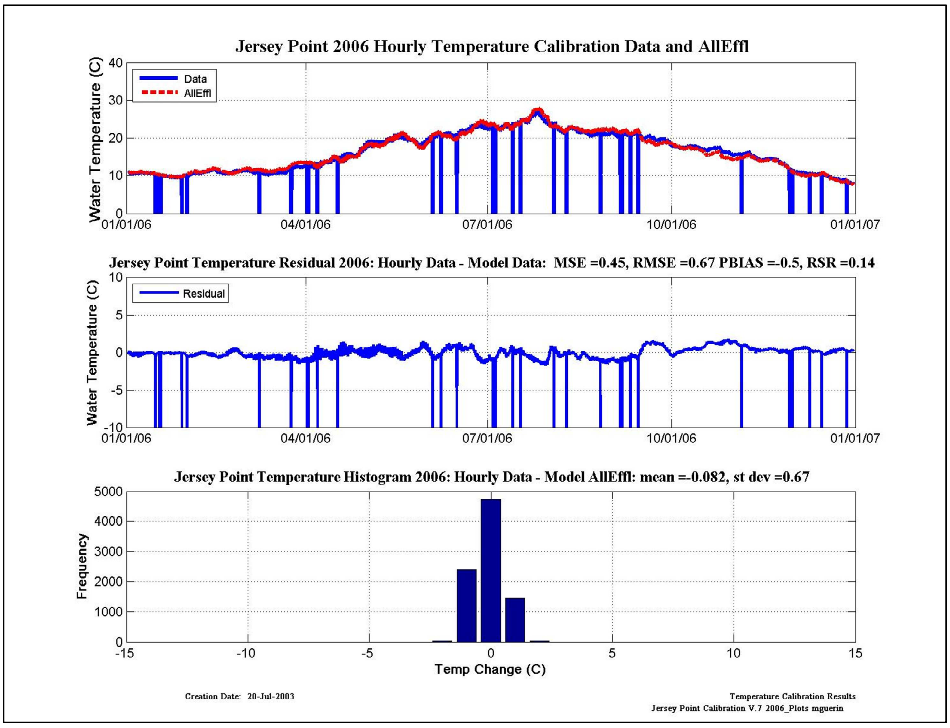


Figure 17-62 Calibration plots in the Abv Normal WY 2005 at RSAN072 on the San Joaquin and at Collinsville.



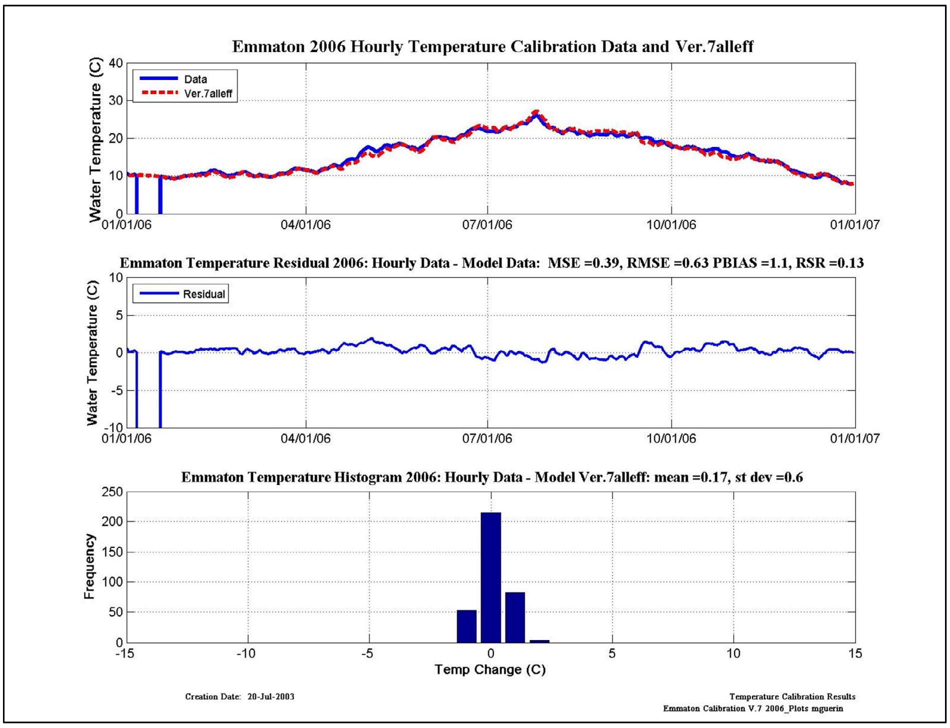
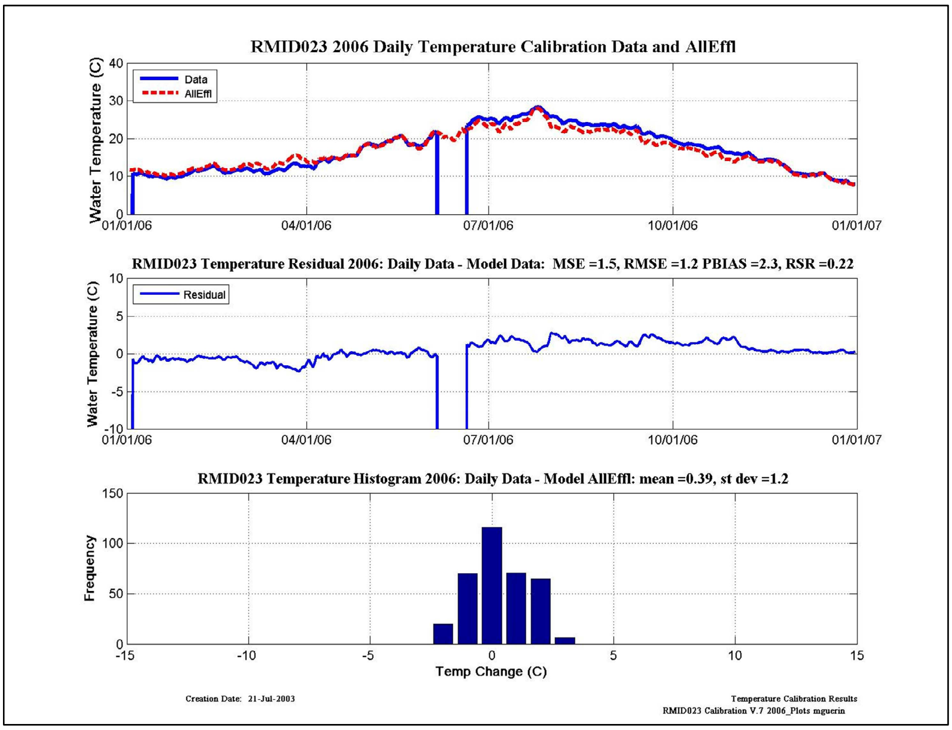


Figure 17-63 Calibration plots in the Wet WY 2006 at Jersey Point and Emmaton.



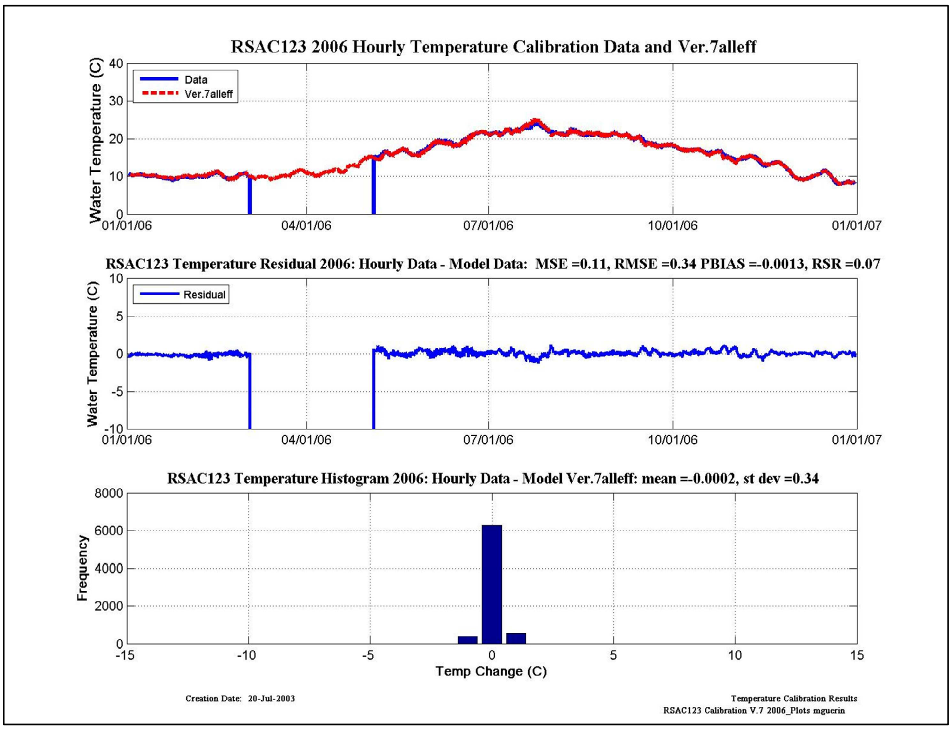
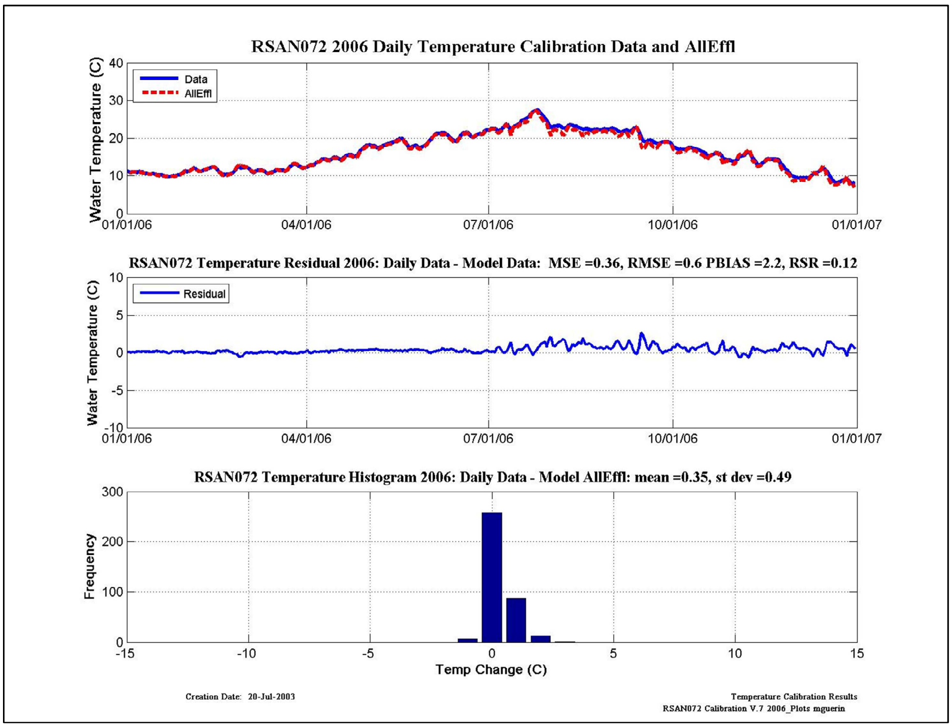


Figure 17-64 Calibration plots in the Wet WY 2006 at RMID023 on Middle R. in the South Delta and at RSAC123 on the upper Sacramento R



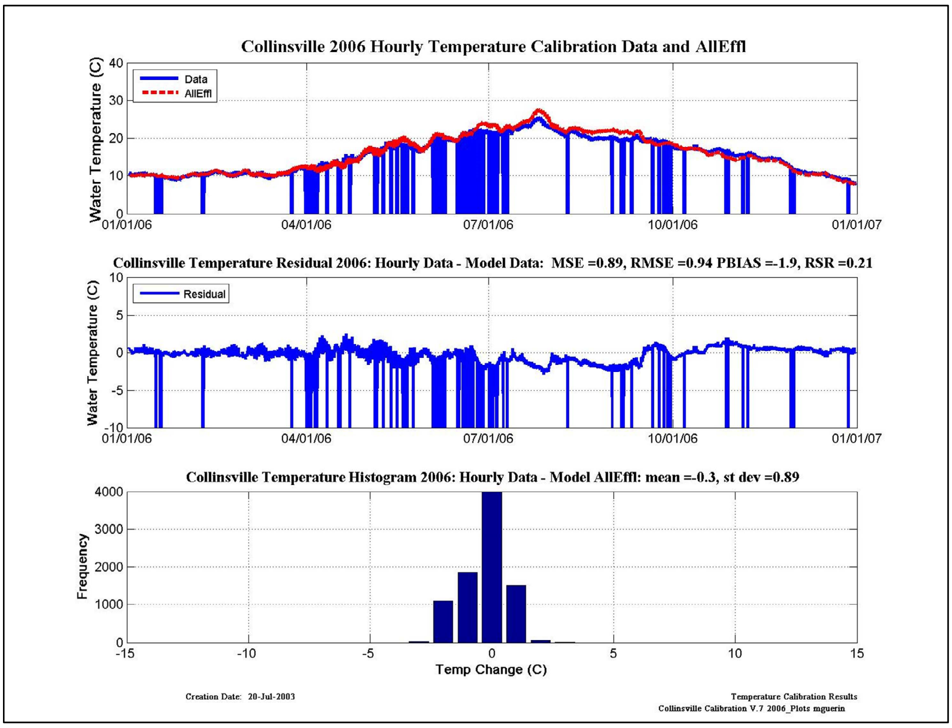
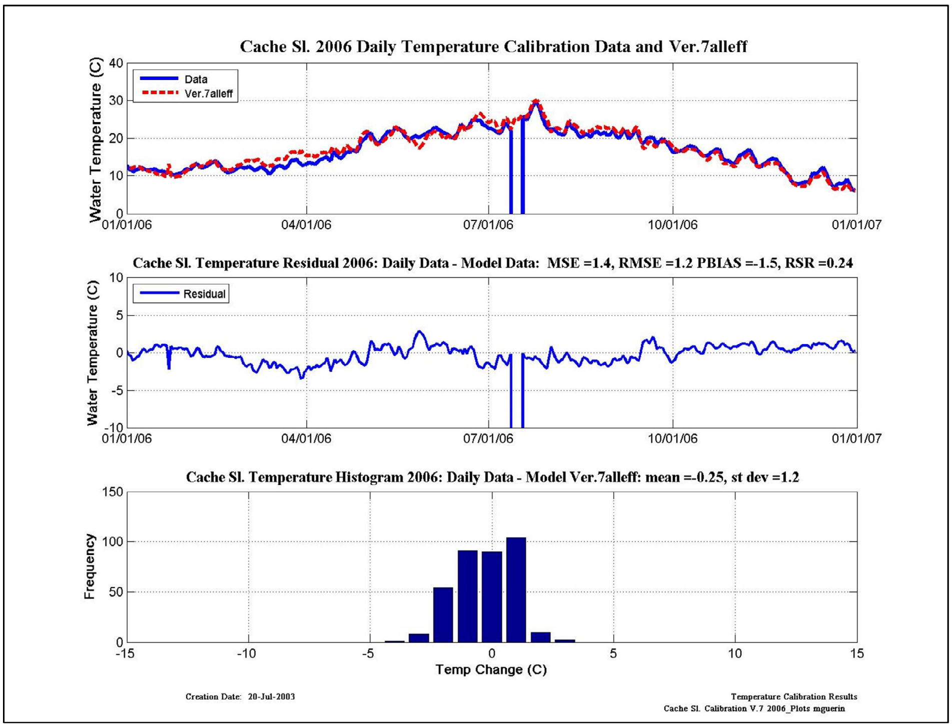


Figure 17-65 Calibration plots in the Wet WY 2006 at RSAN072 on the San Joaquin and at Collinsville.



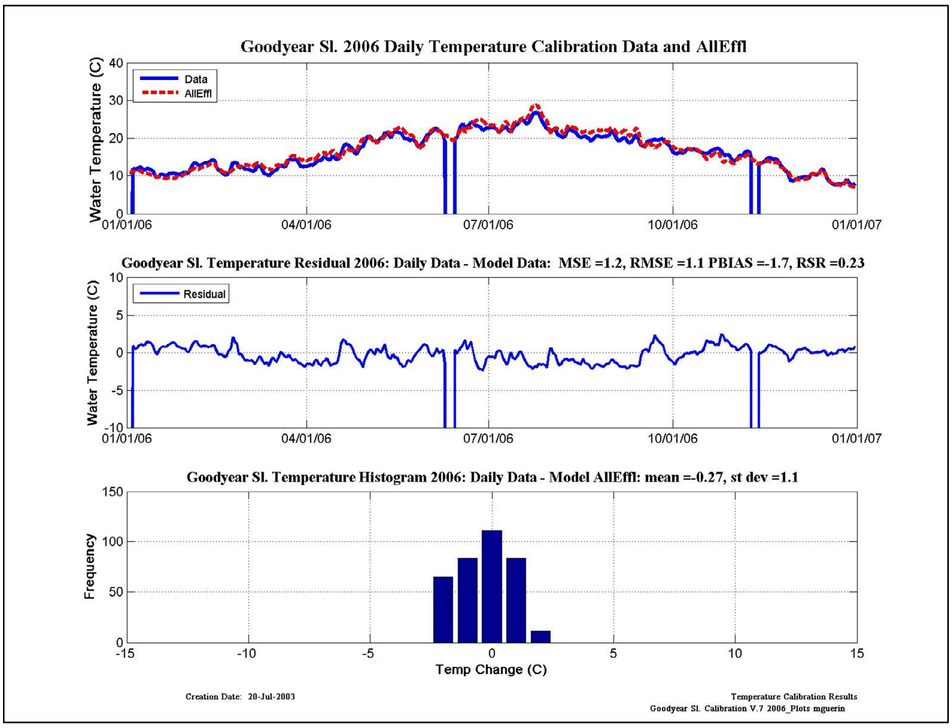


Figure 17-66 Calibration plots in the Wet WY 2006 at Cache Sl. and at Goodyear Sl.

17.9.2 Residual Analysis of the Nutrient Model

The same statistics were calculated in the calibration and validation of the nutrients, as well as residual histograms. The details are covered in Sections 10.3.1 and 10.3.2. Only RSR, PBIAS and NSE were used to evaluate the results as discussed in (Moriasi et al., 2007). Following the recommendations in that paper with one modification (NSE was ruled unsatisfactory when negative, so the satisfactory range was essentially extended), the following categories were used to evaluate the quality of the calibration:

Table 17-13 Categories used to rate the quality of the nutrient calibration/validation.

Performance Rating	RSR	NSE	PBIAS (%)
Very Good	$0.00 \leq$ RSR ≤ 0.50	$0.75 <$ NSE ≤ 1.00	PBIAS < +/- 25
Good	$0.50 <$ RSR ≤ 0.60	$0.65 <$ NSE ≤ 0.75	+/- 25 ≤ PBIAS < +/- 40
Satisfactory	$0.60 <$ RSR ≤ 0.70	$0.00 \leq$ NSE ≤ 0.65	+/- 40 ≤ PBIAS < +/- 70
Unsatisfactory	RSR > 0.7	NSE < 0.0	PBIAS ≥ +/- 70

Although the PBIAS ranges are specific to N- and P-nutrients, the ranges for RSR and NSE are not constituent-specific in the general performance ratings presented in (Moriasi et al, 2007). PBIAS ranges for constituents tend to be more lenient than those listed for streamflow or sediment transport. Thus, we can expect that the ratings for RSR and NSE are quite strict when applied to constituent calibration/validation statistics. To accommodate this observation somewhat, the range for “Satisfactory” was extended to all positive values. The range for RSR was not altered.

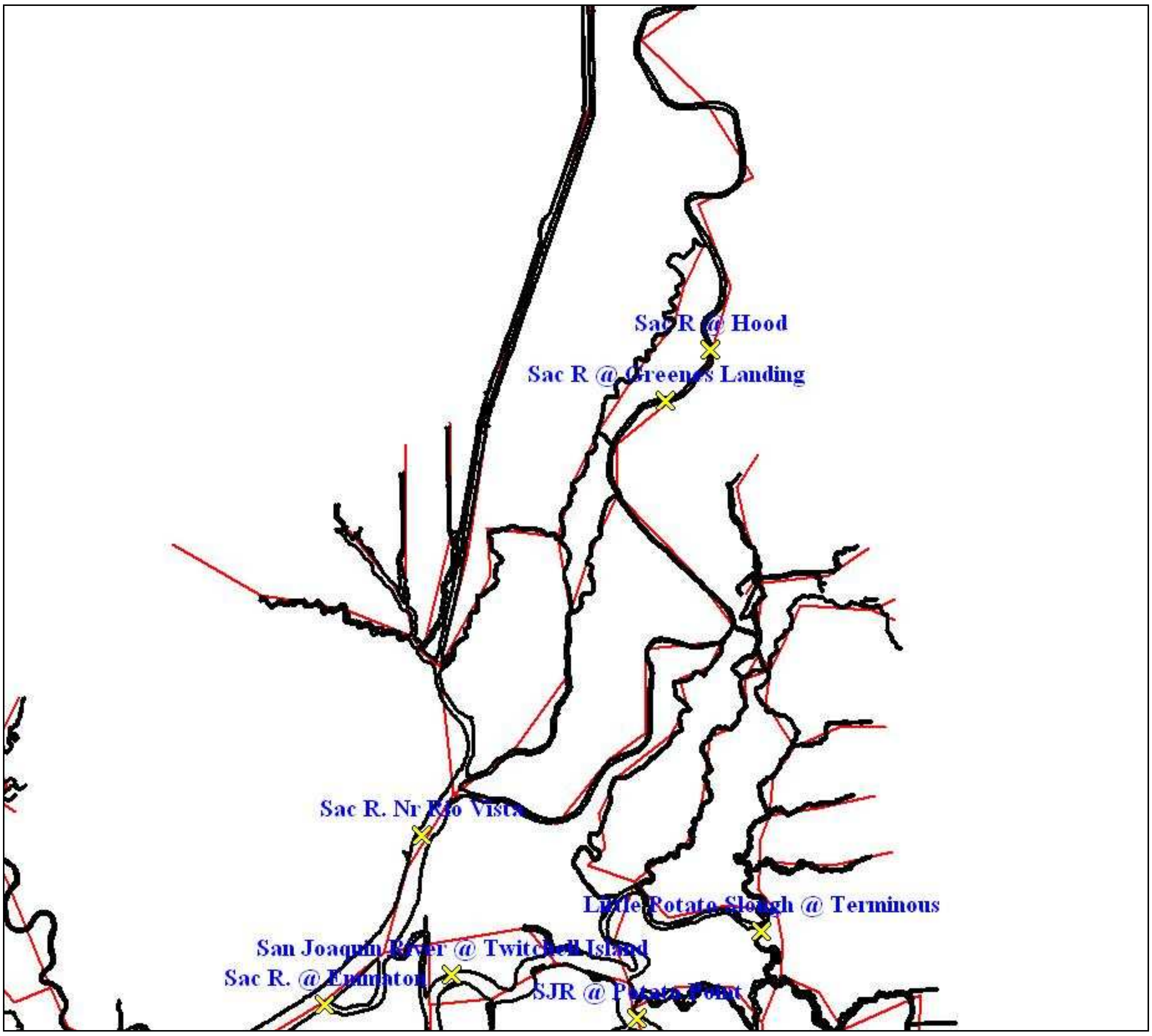


Figure 17-67 Calibration/validation locations in the northern Delta

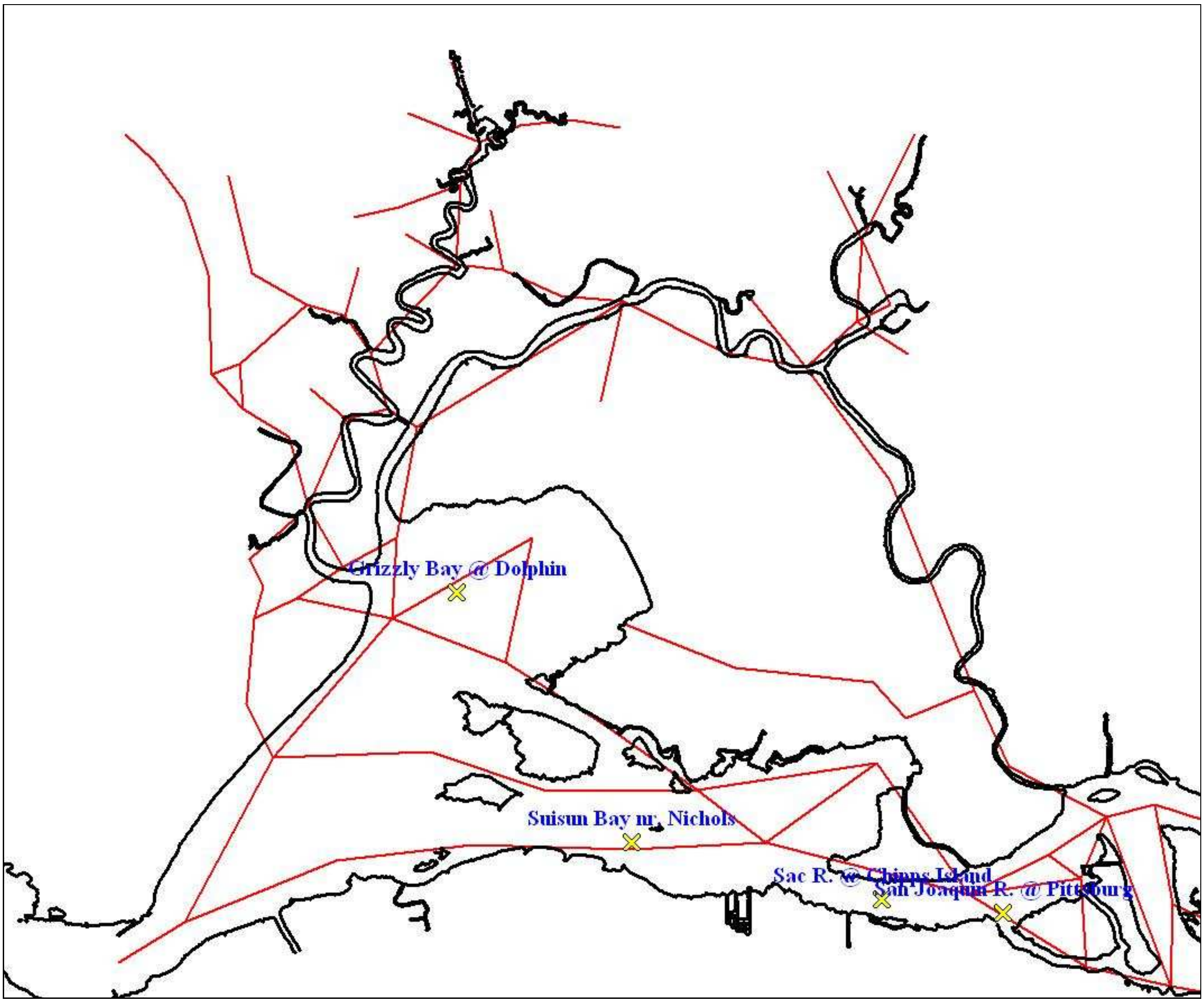


Figure 17-68 Calibration/validation locations in the western Delta.

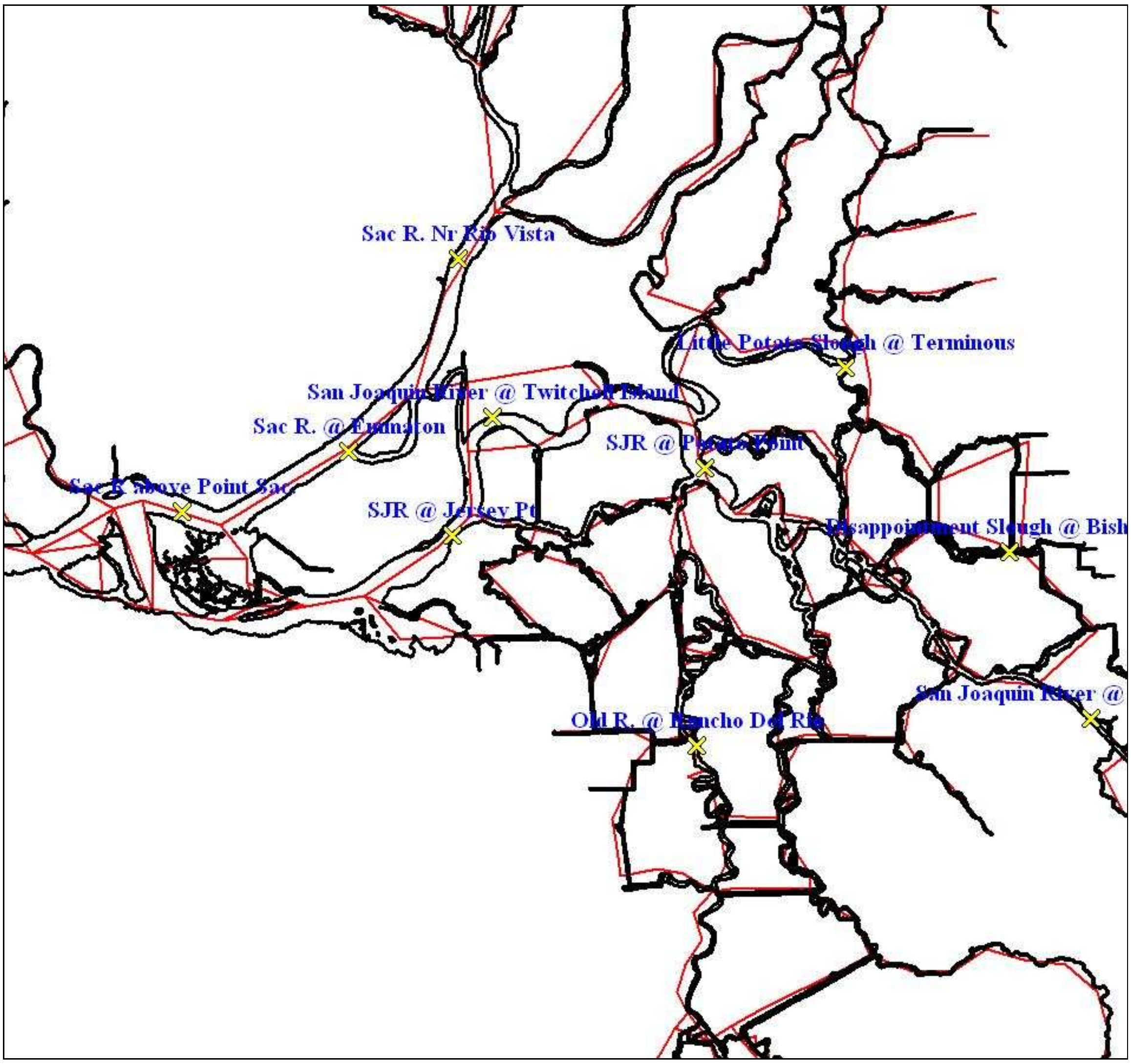


Figure 17-69 Calibration/validation locations in the central Delta.

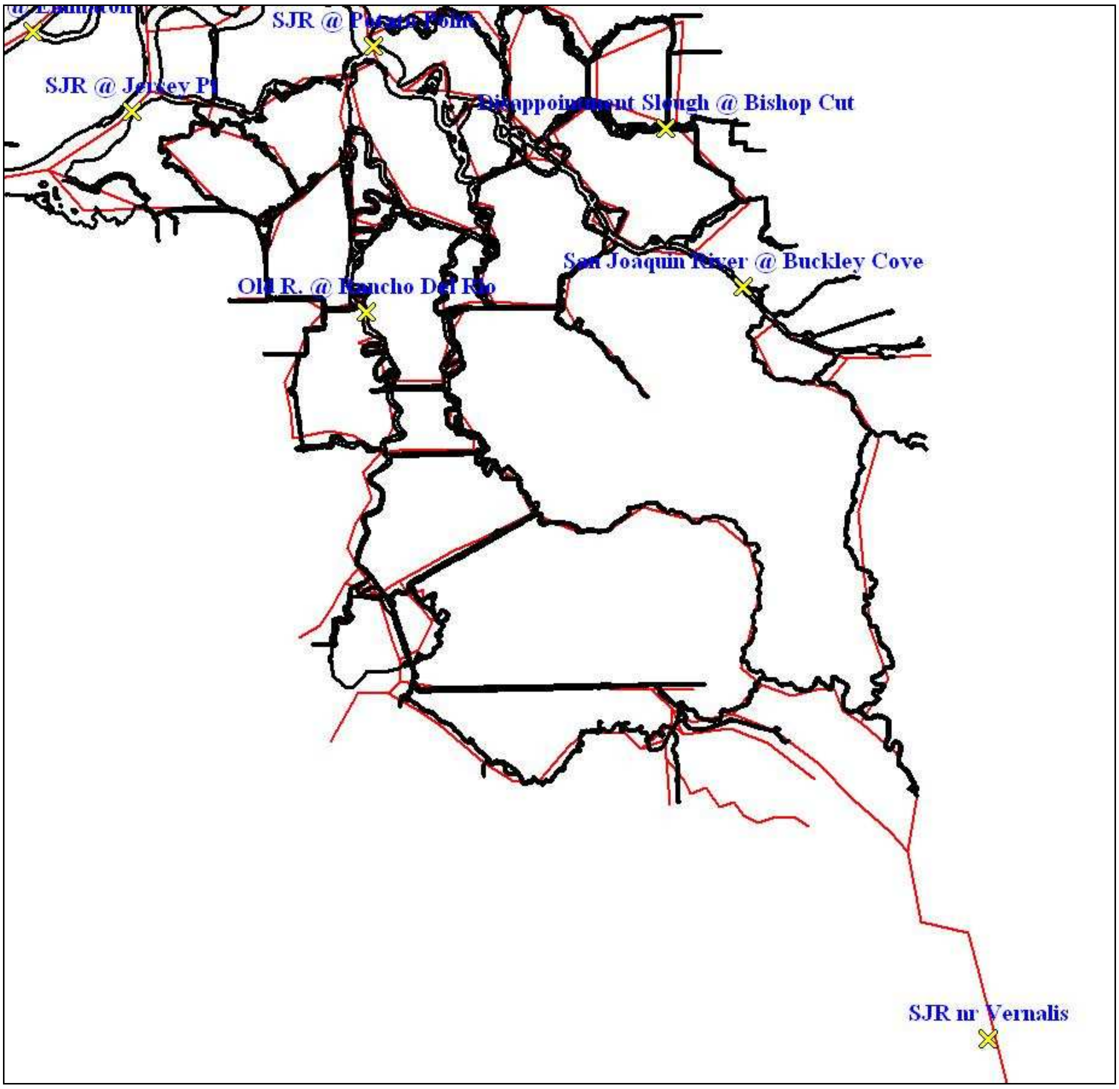


Figure 17-70 Calibration/validation locations in the south Delta.

Table 17-14 Calibration statistics for the Below Normal water Year 2004.

Calibration BN	Mean_Residual	StDev_Residual	NSE_stat	MSE_stat	RMSE_stat	PBIAS_stat	RSR_stat	Mean_data	StDev_data
SJR									
Average	0.73	1.02	0.96	1.80	1.28	4.03	0.25	17.53	5.02
Max	1.25	1.35	0.97	3.37	1.84	6.56	0.33	19.06	5.56
Min	0.21	0.85	0.94	0.76	0.87	1.28	0.18	16.60	4.64
SAC									
Average	0.22	0.78	0.97	0.78	0.88	1.30	0.18	16.39	4.88
Max	0.61	0.97	0.99	1.01	1.00	3.66	0.22	16.89	5.49
Min	-0.33	0.57	0.95	0.47	0.68	-2.07	0.13	15.88	4.49
S Delta									
Average	1.50	1.30	0.95	3.93	1.98	8.36	0.34	17.97	5.79
Max	1.50	1.30	0.95	3.93	1.98	8.36	0.34	17.97	5.79
Min	1.50	1.30	0.95	3.93	1.98	8.36	0.34	17.97	5.79
Cache Sl									
Value	-0.29	1.36	0.92	1.93	1.39	-1.78	0.29	16.48	4.78
Suisun Marsh									
Value	0.37	1.15	0.94	1.45	1.21	2.23	0.25	16.75	4.74

Table 17-15 Full calibration/validation results for ammonia and nitrate+nitrite.

Ammonia

Calibration - Dry	mean_residual	stdev_residual	NSE_stat	MSE_stat	RMSE_stat	PBIAS_stat	RSR_stat	Mean_data	StDev_data
Susiun near Nichols	0.01	0.02	0.86	0.00	0.02	9.19	0.40	0.07	0.05
Grizzly	0.01	0.04	-2.97	0.00	0.04	7.79	2.01	0.09	0.02
Potato Point	0.01	0.03	0.60	0.00	0.03	14.63	0.70	0.10	0.05
Old River at RDR	0.00	0.02	0.42	0.00	0.02	-4.81	0.76	0.06	0.03
Point Sacramento	0.01	0.02	0.90	0.00	0.02	9.40	0.35	0.07	0.05
Buckley Cove	0.00	0.11	0.95	0.01	0.11	-0.48	0.23	0.64	0.49
Greens/Hood	-0.01	0.02	0.97	0.00	0.02	-1.03	0.17	0.53	0.13
Disappointment Sl.	0.00	0.05	-1.22	0.00	0.05	0.65	1.48	0.07	0.03
Calibration - Wet									
Susiun near Nichols	0.00	0.00	0.98	0.00	0.00	-1.21	0.13	0.08	0.03
Grizzly	0.00	0.02	-0.97	0.00	0.02	-4.33	1.41	0.08	0.02
Potato Point	0.00	0.01	0.96	0.00	0.01	1.95	0.20	0.09	0.04
Old River at RDR	0.00	0.03	0.22	0.00	0.03	-6.10	0.89	0.06	0.03
Point Sacramento	0.00	0.01	0.96	0.00	0.01	-2.10	0.19	0.08	0.04
Buckley Cove	0.01	0.08	0.97	0.01	0.08	1.57	0.17	0.45	0.46
Greens/Hood	0.00	0.01	0.99	0.00	0.01	-1.46	0.08	0.29	0.14
Disappointment Sl.	0.00	0.07	0.01	0.01	0.07	3.46	0.99	0.04	0.07

NO3+NO2

Calibration - Dry	mean_residual	stdev_residual	NSE_stat	MSE_stat	RMSE_stat	PBIAS_stat	RSR_stat	Mean_data	StDev_data
Susiun near Nichols	0.07	0.13	0.22	0.02	0.15	19.65	1.01	0.38	0.15
Rio Vista	0.00	0.04	0.88	0.00	0.04	0.23	0.34	0.41	0.10
Grizzly	0.06	0.16	-0.15	0.03	0.17	14.71	1.15	0.43	0.15
Potato Point	-0.02	0.08	0.62	0.01	0.08	-4.19	0.63	0.45	0.13
Old River at RDR	0.05	0.19	0.14	0.04	0.19	10.45	0.95	0.44	0.20
Point Sacramento	0.05	0.11	0.43	0.01	0.12	12.14	0.81	0.38	0.14
Buckley Cove	-0.21	0.64	0.76	0.45	0.67	-9.25	0.52	2.25	1.29
Greens/Hood	-0.01	0.02	0.90	0.00	0.03	-5.44	0.36	0.24	0.07
Disappointment Sl.	0.05	0.11	0.43	0.01	0.12	12.14	0.81	0.38	0.14
Calibration - Wet									
Susiun near Nichols	0.03	0.06	0.60	0.00	0.07	10.57	0.69	0.28	0.10
Rio Vista	-0.01	0.04	0.87	0.00	0.04	-4.43	0.37	0.25	0.10
Grizzly	0.02	0.07	0.73	0.01	0.07	8.23	0.55	0.29	0.13
Potato Point	-0.01	0.05	0.92	0.00	0.05	-2.78	0.29	0.42	0.17
Old River at RDR	0.00	0.16	0.66	0.03	0.16	0.52	0.58	0.49	0.28
Point Sacramento	0.02	0.04	0.83	0.00	0.05	6.10	0.44	0.26	0.11
Buckley Cove	-0.02	0.17	0.94	0.03	0.17	-1.69	0.24	1.26	0.69
Greens/Hood	0.00	0.01	0.93	0.00	0.01	-1.86	0.27	0.16	0.05
Disappointment Sl.	-0.01	0.14	0.86	0.02	0.14	-1.70	0.38	0.51	0.37

Table 17-16 Full calibration/validation results for organic-N and DO.

Organic-N

Calibration - Dry	mean_residual	stdev_residual	NSE_stat	MSE_stat	RMSE_stat	PBIAS_stat	RSR_stat	Mean_data	StDev_data
Susiun near Nichols	0.02	0.10	-2.52	0.01	0.10	8.44	1.91	0.27	0.05
Grizzly	0.04	0.09	-4.15	0.01	0.09	13.44	2.45	0.28	0.04
Potato Point	0.01	0.11	-1.85	0.01	0.11	2.69	1.68	0.27	0.07
Old River at RDR	0.04	0.09	-1.85	0.01	0.10	17.00	1.85	0.26	0.05
Point Sacramento	0.01	0.10	-2.46	0.01	0.10	4.50	1.86	0.27	0.05
Buckley Cove	0.04	0.17	0.63	0.03	0.17	6.66	0.61	0.53	0.28
Greens/Hood	-0.02	0.02	0.96	0.00	0.03	-6.97	0.29	0.30	0.10
Disappointment Sl.	0.13	0.20	-9.87	0.06	0.24	56.96	3.85	0.22	0.06
Calibration - Wet									
Susiun near Nichols	-0.01	0.07	0.42	0.00	0.07	-4.31	0.77	0.22	0.09
Grizzly	0.02	0.09	-0.41	0.01	0.09	8.85	1.20	0.22	0.08
Potato Point	-0.02	0.07	0.42	0.01	0.07	-8.48	0.79	0.25	0.09
Old River at RDR	-0.01	0.09	0.11	0.01	0.09	-2.37	0.94	0.26	0.10
Point Sacramento	-0.01	0.08	0.21	0.01	0.08	-2.40	0.88	0.22	0.09
Buckley Cove	0.01	0.06	0.95	0.00	0.06	1.66	0.23	0.38	0.25
Greens/Hood	-0.01	0.01	0.99	0.00	0.02	-4.34	0.15	0.24	0.12
Disappointment Sl.	0.10	0.23	-6.69	0.06	0.24	42.24	2.99	0.23	0.08

DO

Calibration - Dry	mean_residual	stdev_residual	NSE_stat	MSE_stat	RMSE_stat	PBIAS_stat	RSR_stat	Mean_data	StDev_data
Susiun near Nichols	-0.08	0.26	0.88	0.07	0.27	-0.89	0.36	9.21	0.75
Grizzly	-0.09	0.27	0.90	0.08	0.28	-0.96	0.33	9.08	0.86
Little Potato Sl at Terminous	-0.21	0.73	-0.16	0.56	0.75	-2.39	1.11	8.62	0.67
Potato Point	-0.04	0.25	0.89	0.06	0.25	-0.41	0.34	8.87	0.73
Old River at RDR	0.06	0.34	0.83	0.12	0.34	0.70	0.42	8.57	0.81
Twitchell	-0.04	0.15	0.95	0.03	0.16	-0.46	0.23	9.01	0.70
Point Sacramento	-0.02	0.04	0.92	0.00	0.04	-7.85	0.31	0.20	0.14
Buckley Cove	0.16	0.26	-0.41	0.09	0.30	53.33	1.40	0.30	0.22
Greens/Hood	-0.04	0.15	0.95	0.03	0.16	-0.46	0.23	9.01	0.70
Calibration - Wet									
Susiun near Nichols	0.08	0.67	0.24	0.45	0.67	0.84	0.87	9.26	0.76
Grizzly	-0.05	0.19	0.95	0.04	0.20	-0.58	0.22	9.21	0.90
Little Potato Sl at Terminous	-0.11	0.54	0.39	0.30	0.55	-1.32	0.80	8.70	0.69
Potato Point	0.05	0.22	0.90	0.05	0.22	0.62	0.32	8.81	0.70
Old River at RDR	0.20	0.40	0.69	0.20	0.45	2.35	0.62	8.48	0.73
Twitchell	0.08	0.30	0.83	0.10	0.31	0.93	0.42	8.98	0.74
Point Sacramento	0.02	0.15	-1.06	0.02	0.15	12.25	1.44	0.17	0.10
Buckley Cove	0.08	0.17	0.38	0.04	0.19	22.11	0.86	0.35	0.22
Greens/Hood	0.00	0.01	0.97	0.00	0.01	0.56	0.16	0.16	0.05

Table 17-17 Full calibration/validation results for Chl-a/Algae and PO_4.

Chl-a/Algae

Calibration - Dry	mean_residual	stdev_residual	NSE_stat	MSE_stat	RMSE_stat	PBIAS_stat	RSR_stat	Mean_data	StDev_data
Point Sacramento	-0.02	0.04	0.92	0.00	0.04	-7.85	0.31	0.20	0.14
Susiun near Nichols	-0.02	0.06	0.86	0.00	0.06	-9.80	0.40	0.20	0.15
Rio Vista	0.00	0.09	0.73	0.01	0.08	-0.04	0.51	0.24	0.16
SJR at Pittsburg	0.02	0.07	0.62	0.01	0.07	12.87	0.62	0.14	0.12
Buckley Cove	0.16	0.26	-0.41	0.09	0.30	53.33	1.40	0.30	0.22
Greens/Hood	0.00	0.03	0.89	0.00	0.03	-3.01	0.34	0.16	0.10
Disappointment Sl.	-0.06	0.79	0.18	0.62	0.79	-5.34	0.90	1.19	0.87
Calibration - Wet									
Point Sacramento	0.02	0.15	-1.06	0.02	0.15	12.25	1.44	0.17	0.10
Susiun near Nichols	0.03	0.18	-2.44	0.03	0.18	18.71	1.87	0.16	0.10
Rio Vista	0.02	0.12	-1.35	0.02	0.12	10.60	1.54	0.18	0.08
SJR at Pittsburg	0.03	0.05	0.52	0.00	0.06	20.57	0.76	0.12	0.08
Buckley Cove	0.08	0.17	0.38	0.04	0.19	22.11	0.86	0.35	0.22
Greens/Hood	0.00	0.01	0.97	0.00	0.01	0.56	0.16	0.16	0.05
Disappointment Sl.	0.00	0.36	0.71	0.13	0.36	-0.15	0.54	0.93	0.67

PO4

Calibration - Dry	mean_residual	stdev_residual	NSE_stat	MSE_stat	RMSE_stat	PBIAS_stat	RSR_stat	Mean_data	StDev_data
Susiun near Nichols	-0.17	0.12	0.22	0.04	0.20	-51.60	1.53	0.32	0.13
Grizzly	-0.02	0.13	-0.90	0.02	0.13	-5.07	1.38	0.34	0.10
Potato Point	0.03	0.13	-1.55	0.02	0.13	12.52	1.63	0.24	0.08
Old River at RDR	-0.14	0.07	0.23	0.03	0.16	-59.69	1.98	0.24	0.08
Point Sacramento	-0.07	0.16	-0.43	0.03	0.18	-19.18	1.28	0.35	0.14
Buckley Cove	0.00	0.06	0.81	0.00	0.06	1.49	0.43	0.25	0.14
Greens/Hood	-0.01	0.02	0.84	0.00	0.02	-9.79	0.49	0.12	0.04
Disappointment Sl.	-0.10	0.06	-1.33	0.01	0.11	-48.66	2.91	0.20	0.04
Calibration - Wet									
Susiun near Nichols	-0.07	0.06	0.31	0.01	0.10	-42.37	1.24	0.17	0.08
Grizzly	0.02	0.11	-0.49	0.01	0.11	7.24	1.23	0.22	0.09
Potato Point	0.07	0.11	-6.19	0.02	0.13	53.18	3.16	0.13	0.04
Old River at RDR	-0.07	0.05	-0.53	0.01	0.09	-49.94	2.25	0.15	0.04
Point Sacramento	0.03	0.10	-0.83	0.01	0.11	18.54	1.40	0.17	0.08
Buckley Cove	-0.01	0.02	0.95	0.00	0.02	-3.72	0.23	0.14	0.09
Greens/Hood	-0.01	0.01	0.89	0.00	0.01	-9.50	0.44	0.06	0.02
Disappointment Sl.	-0.06	0.06	-1.04	0.01	0.08	-40.38	1.95	0.14	0.04

17.10 Solution Chemistry and EQ 3/6 calculations

17.10.1 Concentrations of Ammonium Ion and Ammonia

The database in EQ3/6 (Wolery, 1997) was used to calculate the equilibrium concentrations of NH_3 (*aq*) and NH_4^+ at 25°C. The equilibrium reaction constant for the association reaction:

$$NH_4^+ \leftrightarrow NH_3(aq) + H^+ \quad \text{(A7)}$$

is given by:

$$K_{NH_4^+} = \frac{[H^+][NH_3]}{[NH_4^+]} \quad \text{(A8)}$$

where the activity coefficients have not been explicitly included for clarity and simplicity, and the terms in the brackets are expressed in mole kg^{-1} of solution (molality). At 25°C and one atmosphere of pressure, the logarithm of this reaction, log(K), is -9.24. Assuming the concentrations of NH_3 and NH_4^+ are equal, these terms cancel in equation (A8), we see that the pH of this solution would be -9.24 (approximately). Setting log ($[H^+]$) = -8.0, i.e. pH = 8.0, we see the ratio of $[NH_3]$ to $[NH_4^+]$ is $10^{-1.24}$ = 0.0575 (approximately). In other words, about 5.8 % of the total is present as NH_3. Similarly, at pH = 7.0, only 0.58% of the total is present as NH_3.

17.10.2 Water Chemistry at the Sacramento and San Joaquin boundaries.

R. Dahlgren supplied a database of comprehensive water chemistry measurements at several locations near the boundary of the Delta and in the tributaries (see Figure 7-4), The measurements were collected approximately every two weeks, and they varied in total time span in the years from 2000 to 2005, depending on location (Chow et al, 2007).

In order to get a general understanding of the average chemistry of the waters at the Freeport and Vernalis boundaries, EQ3/6 simulations were prepared using these measurements. For the modeling, each measurement type (e.g., NH_4^+-N) was averaged over the entire measurement time span. Nitrite (NO_2^-) was not measured – its concentration was set at1.0% of the measured nitrate (NO_3^-) concentration. The equilibrium geochemical model was developed using the average measurements as input, shown in Table VII a, below. The solutions were initially charge balanced at 25°C using the ions of an inert element (Cl^- or Na^+). The temperature was then adjusted to the average, ambient temperature (16.2 or 17.0, as shown in the Table), and a final charge balance was performed using pH. At Vernalis, the initial average pH was -8.0000 and the final pH after charge balancing at the ambient temperature was -8.0966. At Freeport, the initial pH was -7.8500 and the pH after the final adjustment was -7.9259.

The resulting speciation chemistry for each location is shown in Table A. VII b indicating the major species in each solution. As expected, at Freeport the ionic strength of the solution was low, ~I=0.0024, where I is the ionic strength in mol L^{-1}. At Vernalis, the ionic strength of the solution was an order of magnitude higher, ~I=0.0109. As shown in Table A.VII b., in each location on average NH_4^+ comprised about 97% of the total ammonia in solution.

Another interesting feature of the solutions revealed by the speciation modeling is that both solutions are supersaturated with respect to atmospheric CO_2 (g). This is certainly due to biological activity in solution, with algae releasing CO_2 in respiring. In equilibrium with the atmosphere and in the absence of biological activity, the partial pressure of CO_2 (g) would yield a concentration of about log(CO_2) = -3.5. At Vernalis, calculations indicate that on average the water is supersaturated with respect to CO_2 (g) with log(CO_2) = -3.005. At Freeport, log(CO_2) -3.0507, and so biological activity is lower in these waters as expected. In either case, CO_2 (g) would be out-gassing from solution (the mass transfer would be from water to atmosphere). We can conclude that the pH of the waters would generally not be controlled by transfer of CO_2 (g) from the atmosphere to the waters[19], but instead by other factors (such as the production of CO_2 (g) from the biological activity).

[19] CO_2 (g) dissociates in aqueous solutions to form HCO_3^- and H^+.

Table 17-18 Average Solution Chemistry Used as Input for in Speciation Modeling

	Units	Freeport Chemistry	Units	Vernalis Chemistry
Temp	**°C**	16.2	**°C**	17.0
pH		7.85		8.00
HCO3-	**Moles/kg**	1.43E-03	**Moles/L**	2.33E-03
Na+	**Moles/L**	3.88E-04	**Moles/L**	3.67E-03
K+	**Moles/L**	2.88E-05	**Moles/L**	5.60E-05
Mg++	**Moles/L**	3.01E-04	**Moles/L**	8.88E-04
Ca++	**Moles/L**	3.32E-04	**Moles/L**	1.10E-03
Cl-	**Moles/L**	1.43E-04	**mg/L**	1.06E+02
NH3(aq)	**mg/L**	3.65E-02	**mg/L**	7.30E-02
NO3-	**mg/L**	3.98E-01	**mg/L**	9.47E+00
NO2-	**mg/L**	3.98E-03	**mg/L**	9.47E-02
HPO4--	**mg/L**	8.25E-02	**mg/L**	3.60E-01
SO4--	**Moles/L**	6.79E-05	**Moles/L**	1.05E-03
SiO2(aq)	**Moles/L**	2.91E-04	**Moles/L**	2.33E-04

Table 17-19 EQ3/6 Speciation Results

	Vernalis				Freeport		
Basis Species	**Species Accounting For Basis**	**Molality**	**%**		**Species Accounting For Basis**	**Molality**	**%**
Ca++							
	Ca++	1.02E-03	92.26		Ca++	3.25E-04	97.65
	CaSO4(aq)	5.25E-05	4.75		CaHCO3+	4.05E-06	1.22
	CaHCO3+	1.80E-05	1.63		CaCO3(aq)	1.97E-06	5.92E-01
	CaCO3(aq)	1.28E-05	1.16		CaSO4(aq)	1.69E-06	5.07E-01
Cl-							
	Cl-	2.99E-03	99.88		Cl-	1.43E-04	99.96
HCO3-							
	HCO3-	2.34E-03	95.12		HCO3-	1.37E-03	96.08
	CO2(aq)	4.26E-05	1.73		CO2(aq)	3.94E-05	2.76
	CaHCO3+	1.80E-05	7.33E-01		CO3--	5.18E-06	3.64E-01
HPO4--							
	HPO4--	2.16E-06	57.51		HPO4--	5.83E-07	67.74
	MgHPO4(aq)	6.51E-07	17.33		H2PO4-	1.01E-07	11.78
	CaHPO4(aq)	5.42E-07	14.41		MgHPO4(aq)	9.25E-08	10.74
	H2PO4-	2.17E-07	5.77		CaHPO4(aq)	6.86E-08	7.96
	CaPO4-	1.87E-07	4.97		CaPO4-	1.52E-08	1.77
K+							
	K+	5.58E-05	99.54		K+	2.89E-05	99.96
Mg++							
	Mg++	8.12E-04	91.34		Mg++	2.94E-04	97.8
	MgSO4(aq)	5.58E-05	6.27		MgHCO3+	3.58E-06	1.19
	MgHCO3+	1.42E-05	1.6		MgSO4(aq)	2.01E-06	6.68E-01
NH3(aq)							
	NH4+	4.14E-06	96.52		NH4+	2.10E-06	97.64
	NH3(aq)	1.49E-07	3.48		NH3(aq)	5.07E-08	2.36
Na+							
	Na+	3.65E-03	99.3		Na+	3.88E-04	99.72
SO4--							
	SO4--	9.34E-04	88.66		SO4--	6.42E-05	94.41
	MgSO4(aq)	5.58E-05	5.3		MgSO4(aq)	2.01E-06	2.95
	CaSO4(aq)	5.25E-05	4.98		CaSO4(aq)	1.69E-06	2.48
	NaSO4-	1.09E-05	1.03		NaSO4-	9.70E-08	1.43E-01
SiO2(aq)							
	SiO2(aq)	2.24E-04	95.66		SiO2(aq)	2.83E-04	97.21
	HSiO3-	6.71E-06	2.87		HSiO3-	5.37E-06	1.84
	NaHSiO3(aq)	1.73E-06	7.4E-01		Si2O4(aq)	1.27E-06	8.72E-01

	Vernalis				Freeport		
Basis Species	**Species Accounting For Basis**	**Molality**	**%**		**Species Accounting For Basis**	**Molality**	**%**
NO2-							
	NO2-	2.06E-06	100		NO2-	8.67E-08	100
NO3-							
	NO3-	1.52E-04	99.66		NO3-	6.43E-06	99.87

17.11 Scenario Figures

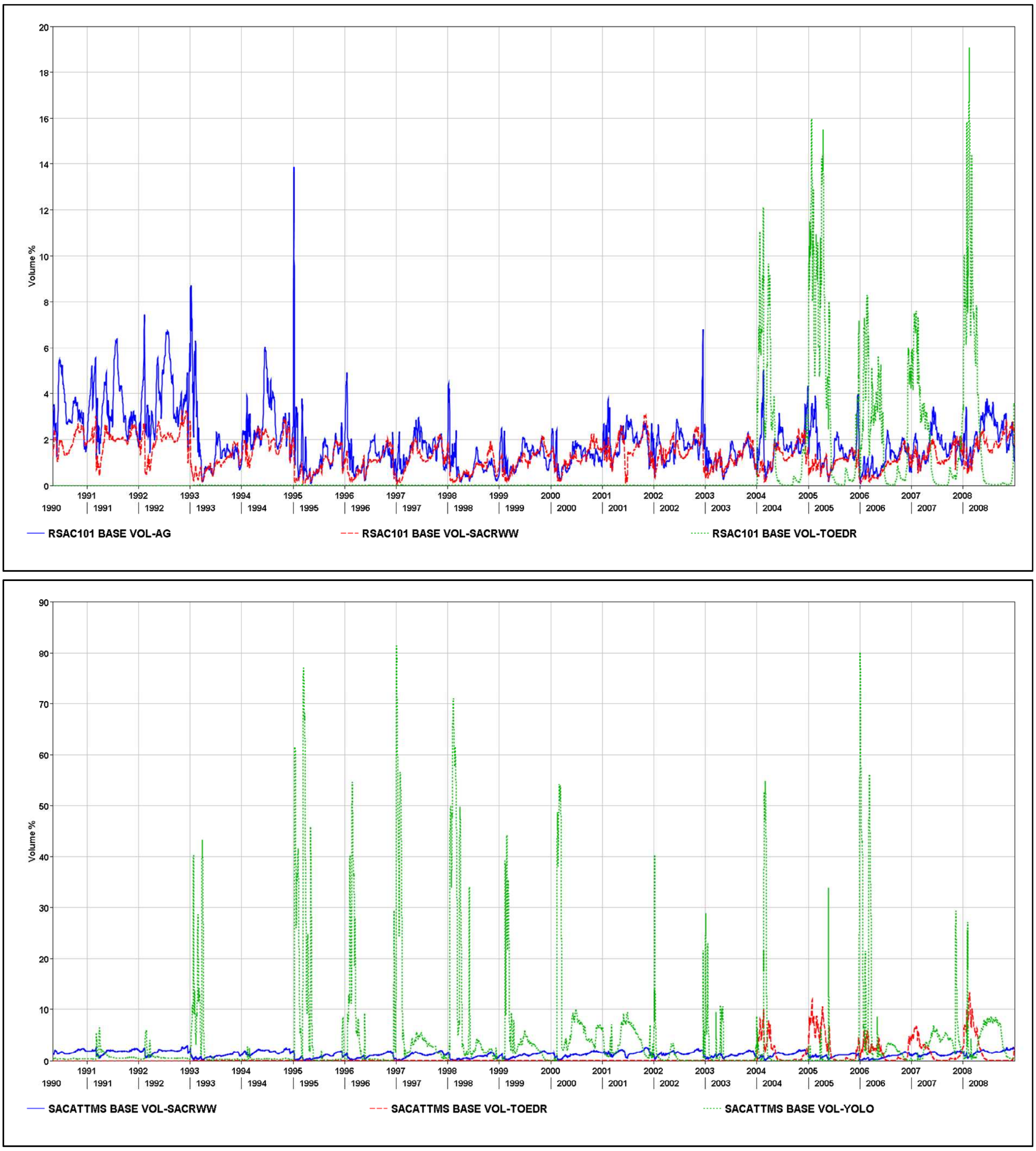


Figure 17-71 Volumetric results at Rio vista (upper0 and in Three Mile Slough (lower).

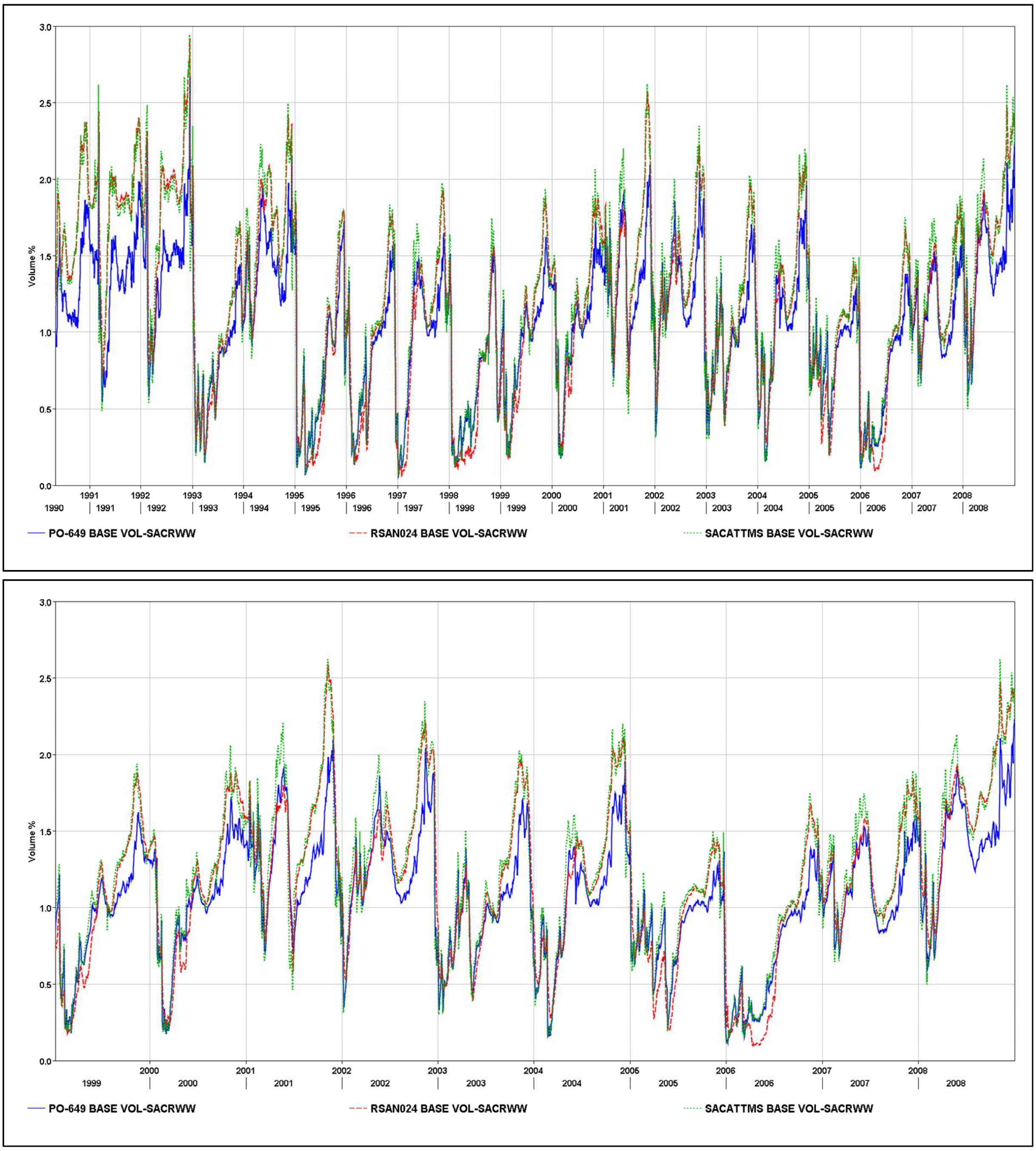


Figure 17-72 Sac Regional effluent volumes along the lower San Joaquin and Sacramento Rivers.

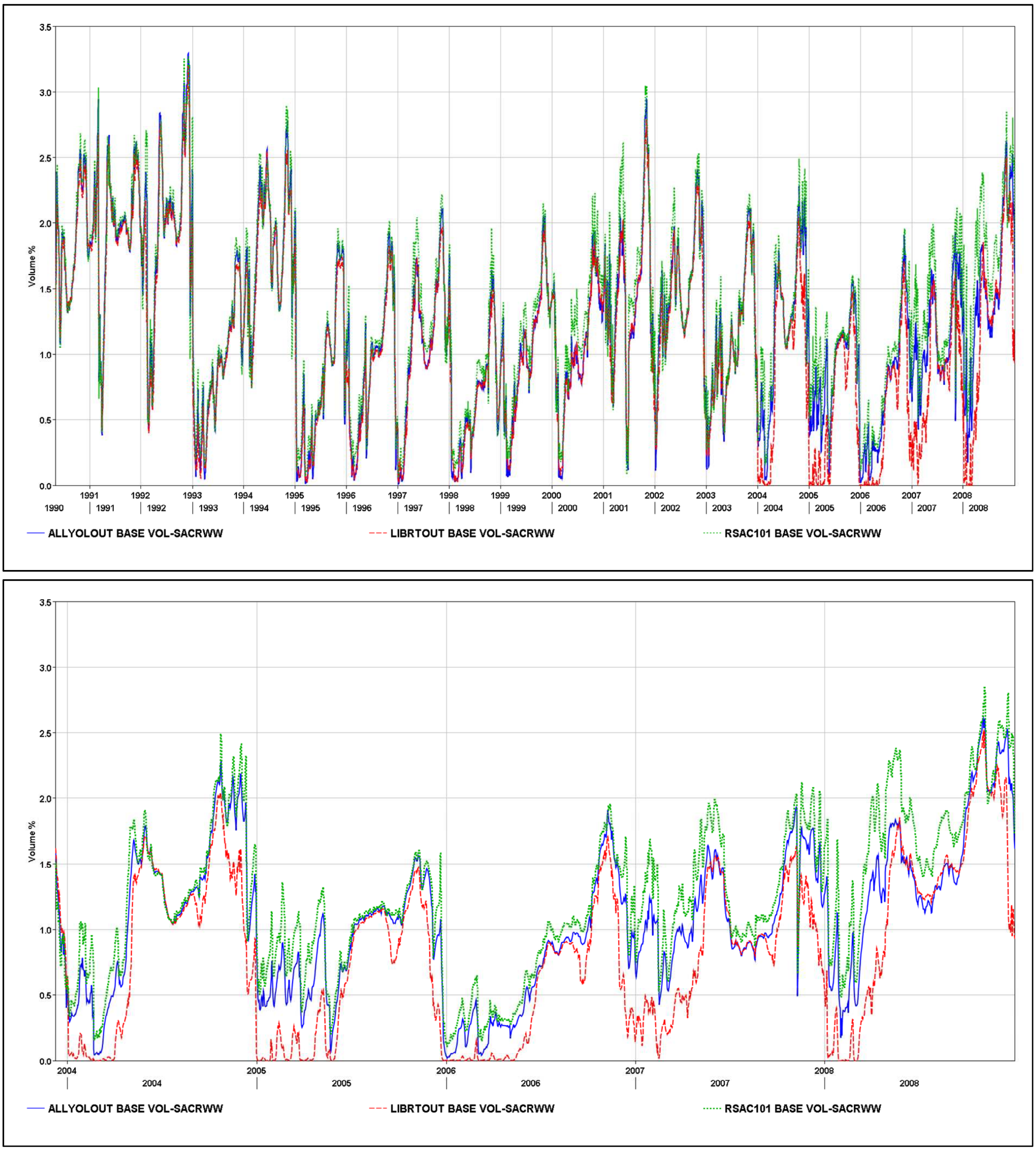


Figure 17-73Volumetric contributions near the Yolo/Cache Slough area.

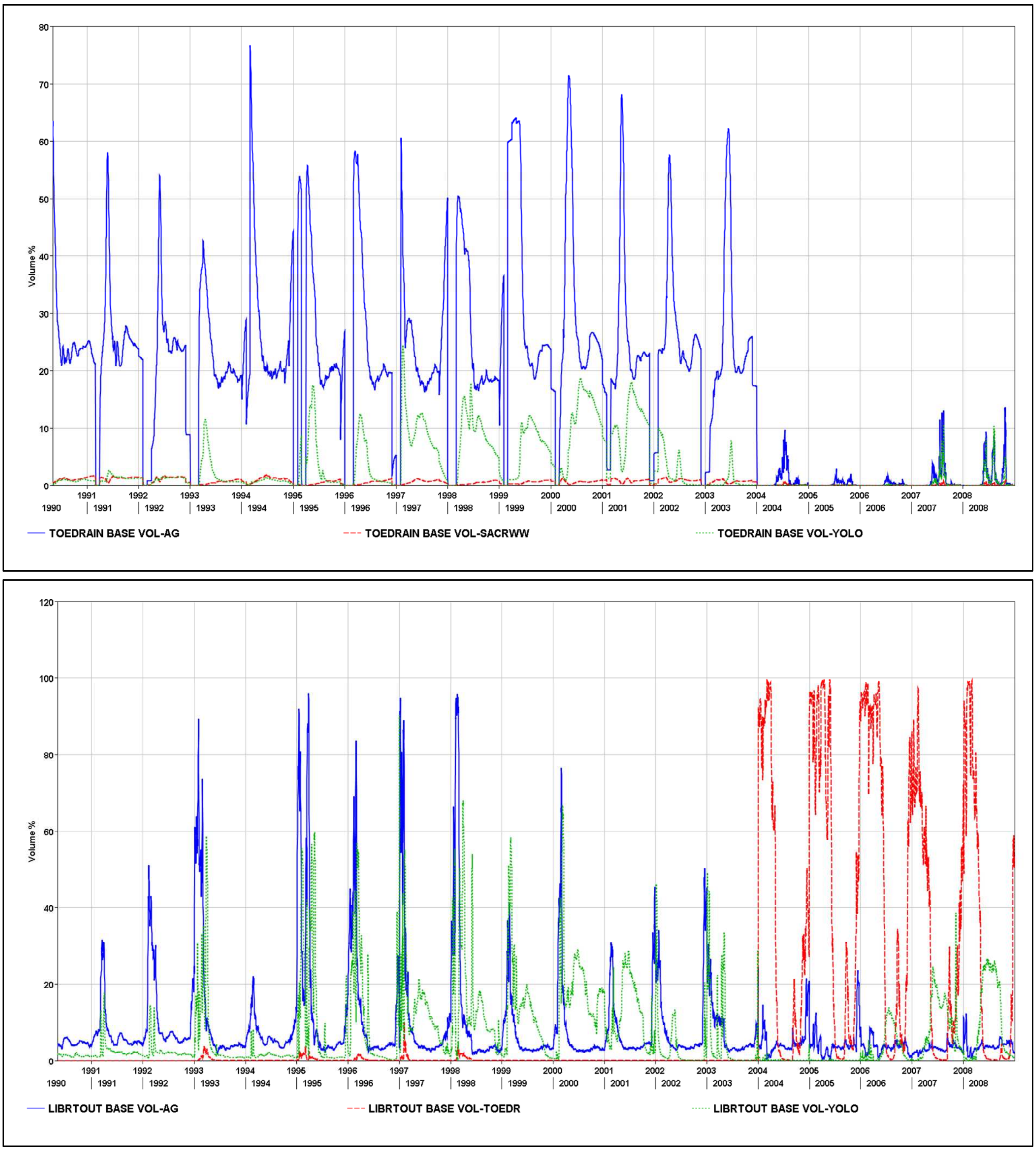


Figure 17-74Volumetric contributions near the Lisbon Toe Drain and the outflow from the Liberty Island area.

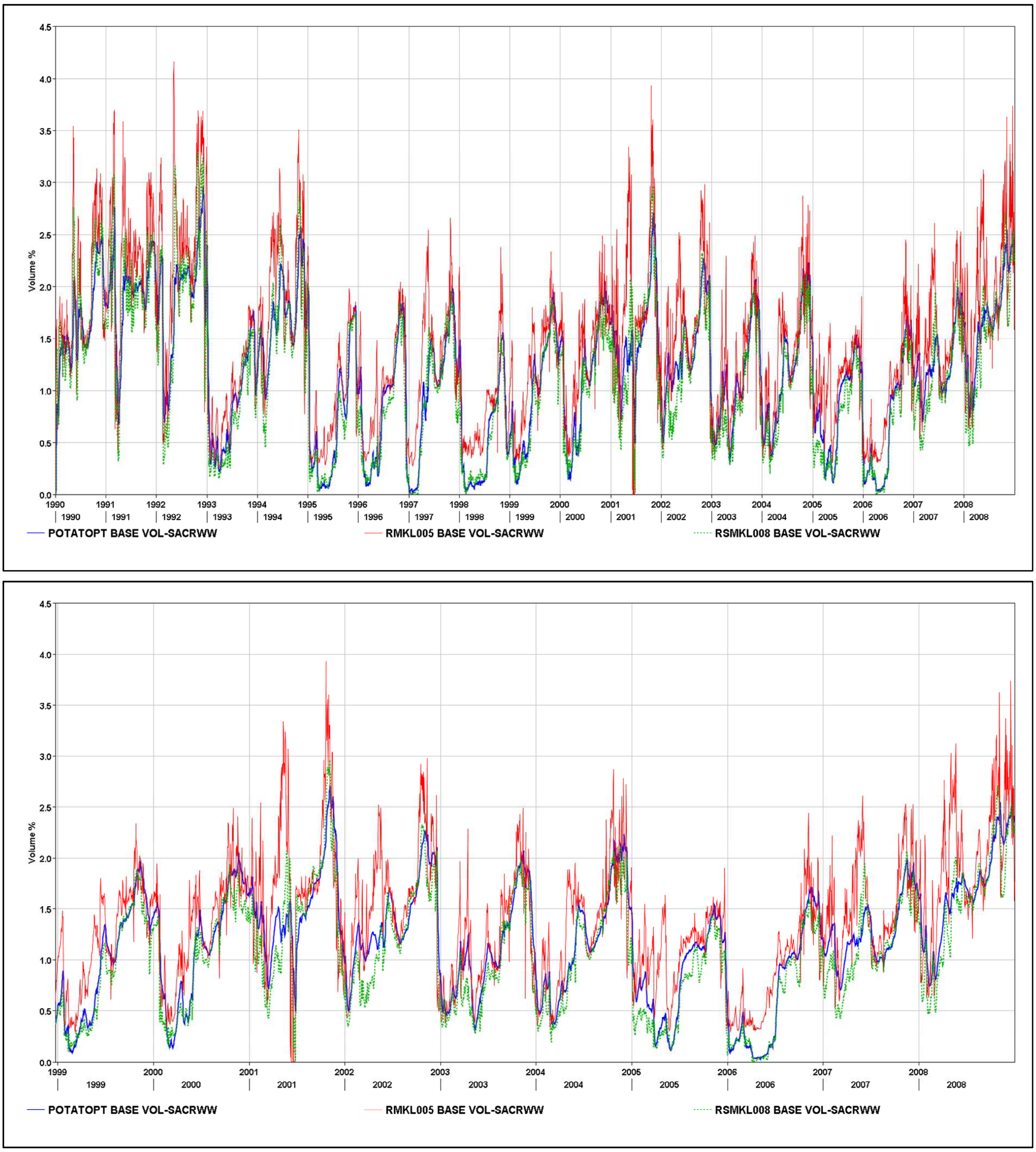


Figure 17-75 Sac Regional effluent volumes in the eastern Delta.

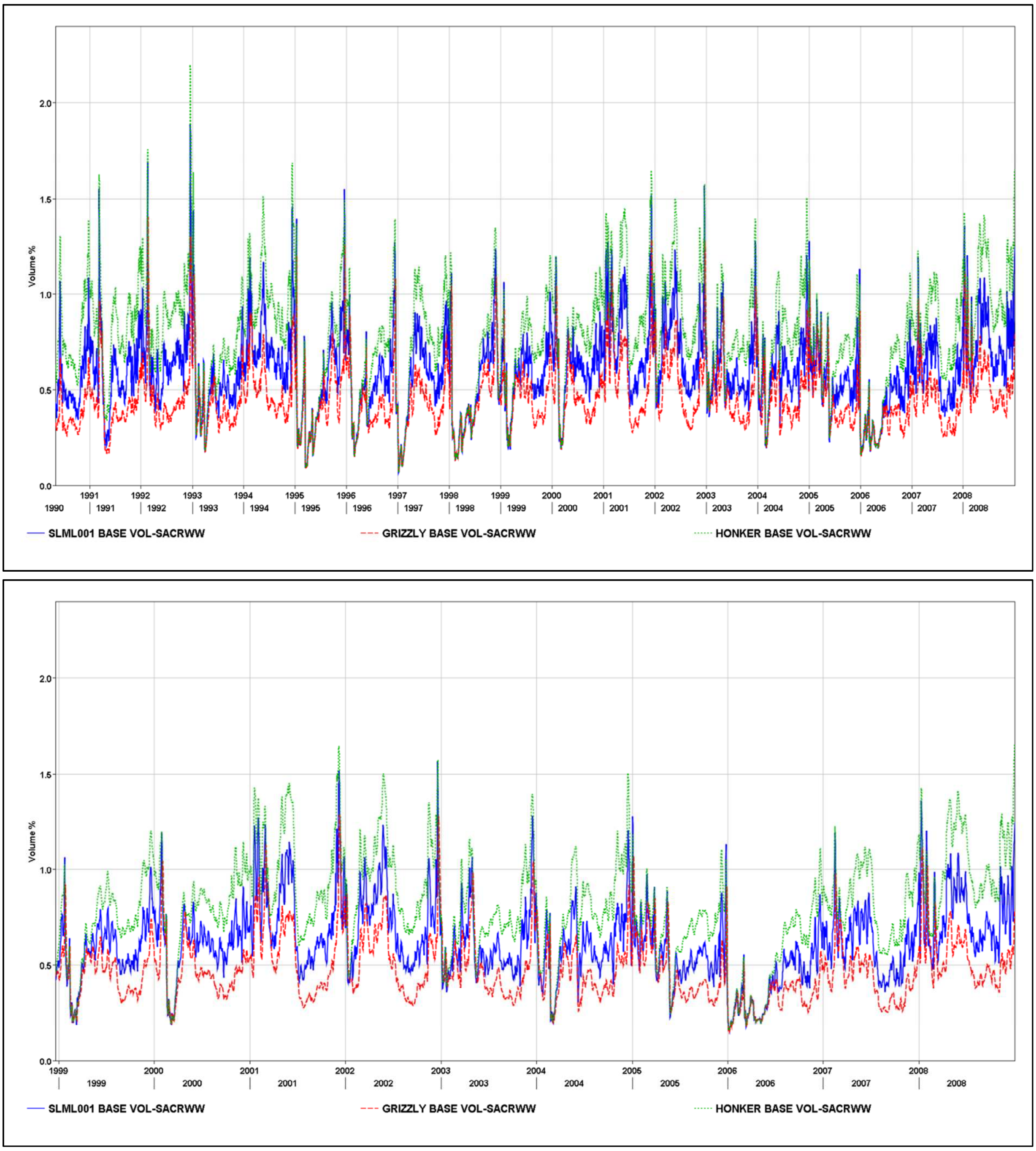


Figure 17-76 Sac Regional effluent volumes along the lower Sacramento River into Grizzly and Honker Bays.

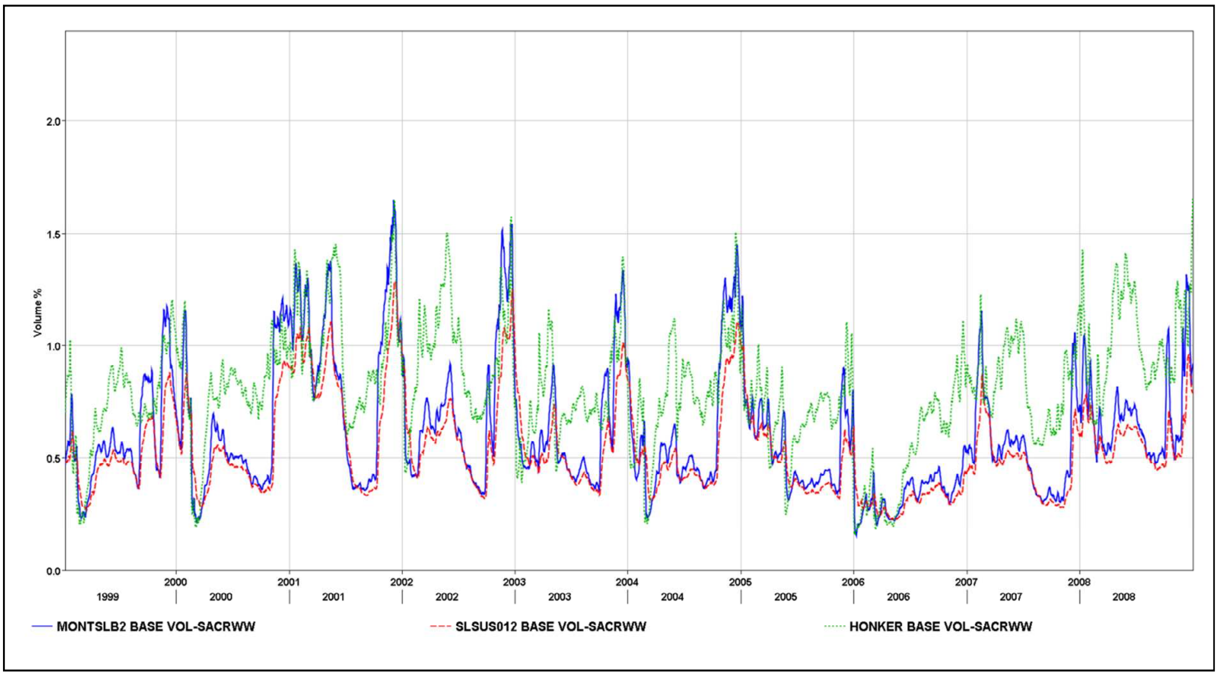
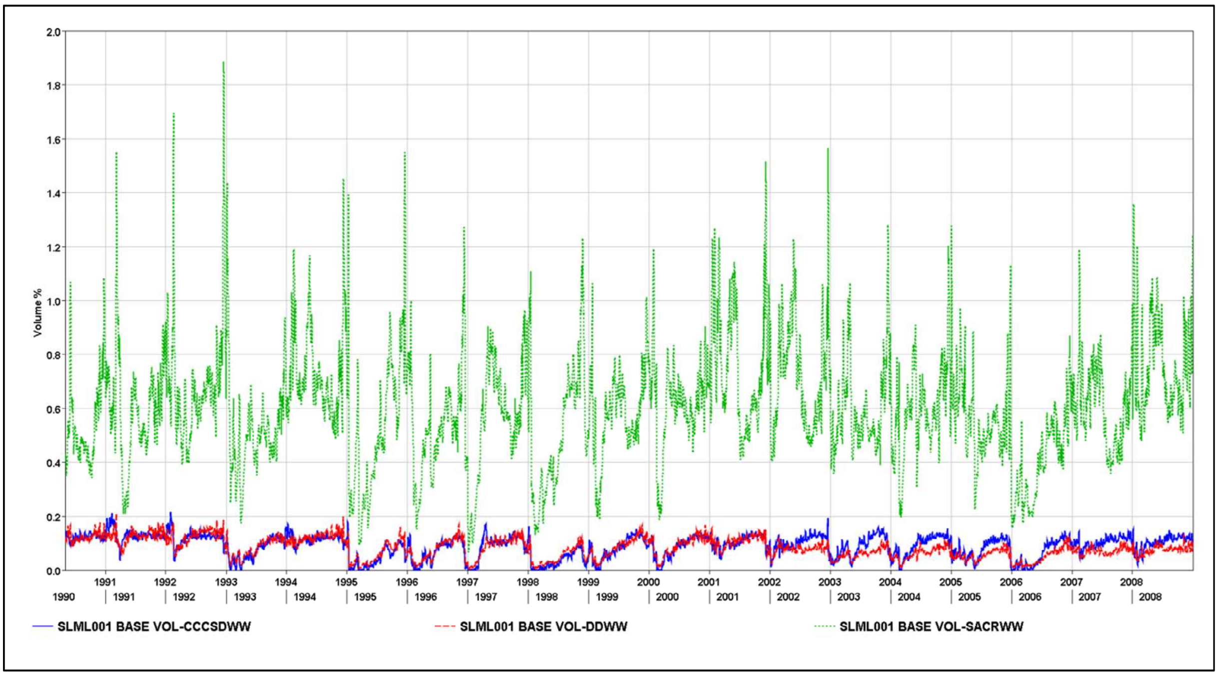


Figure 17-77 Sac Regional effluent volumes in and near Suisun Marsh.



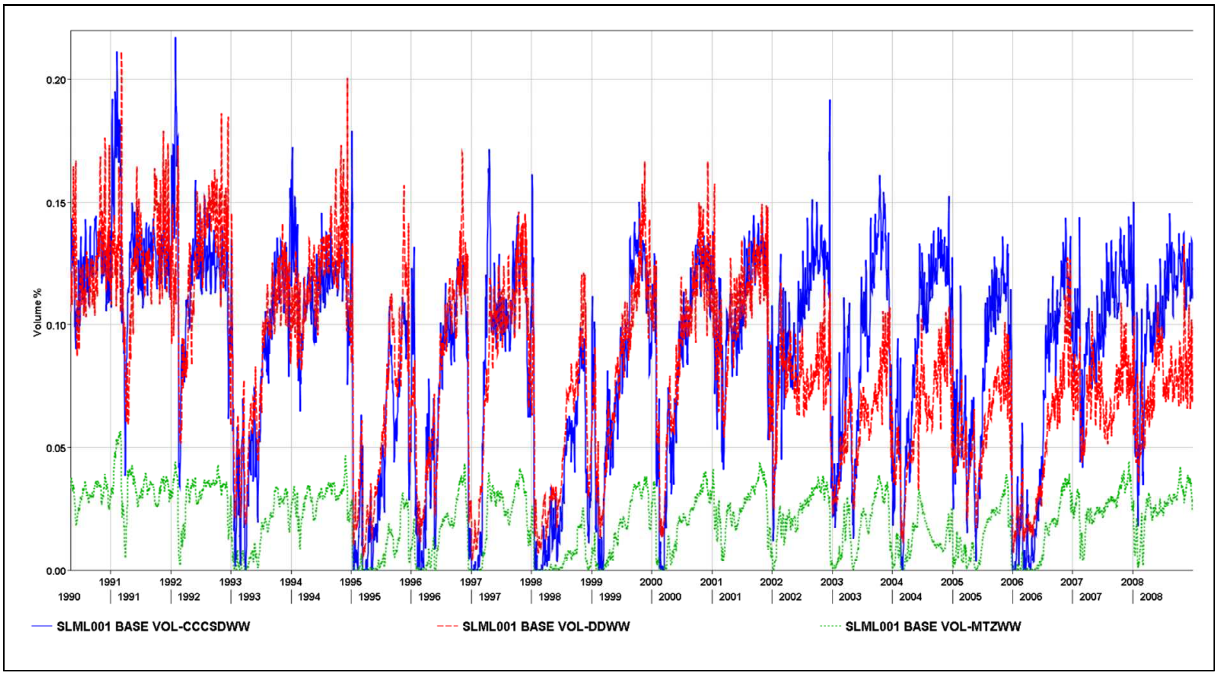


Figure 17-78 Volumetric contributions of smaller WWTP's in the Suisun area.

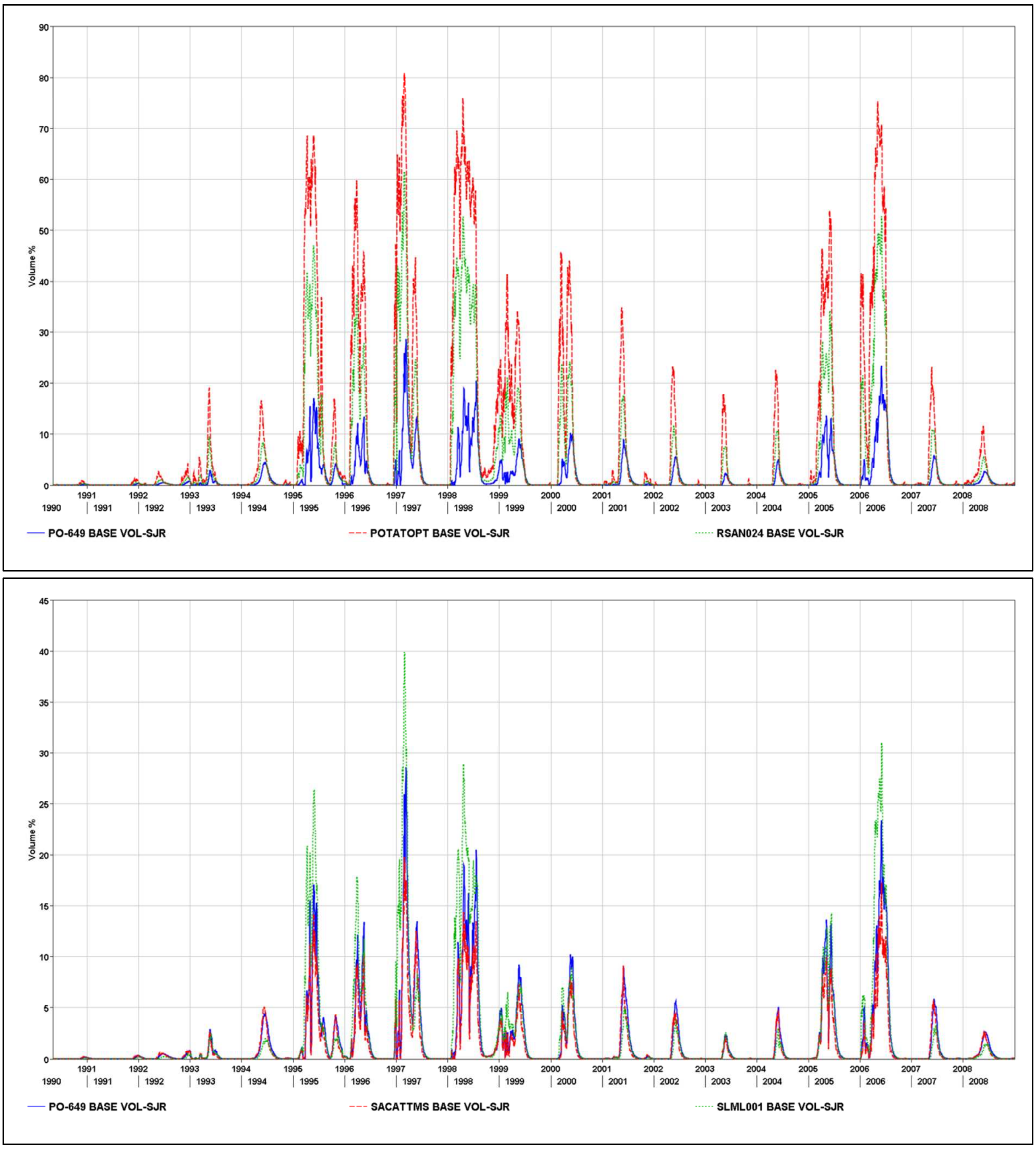


Figure 17-79 Higher volume of San Joaquin River contributions are seasonal.

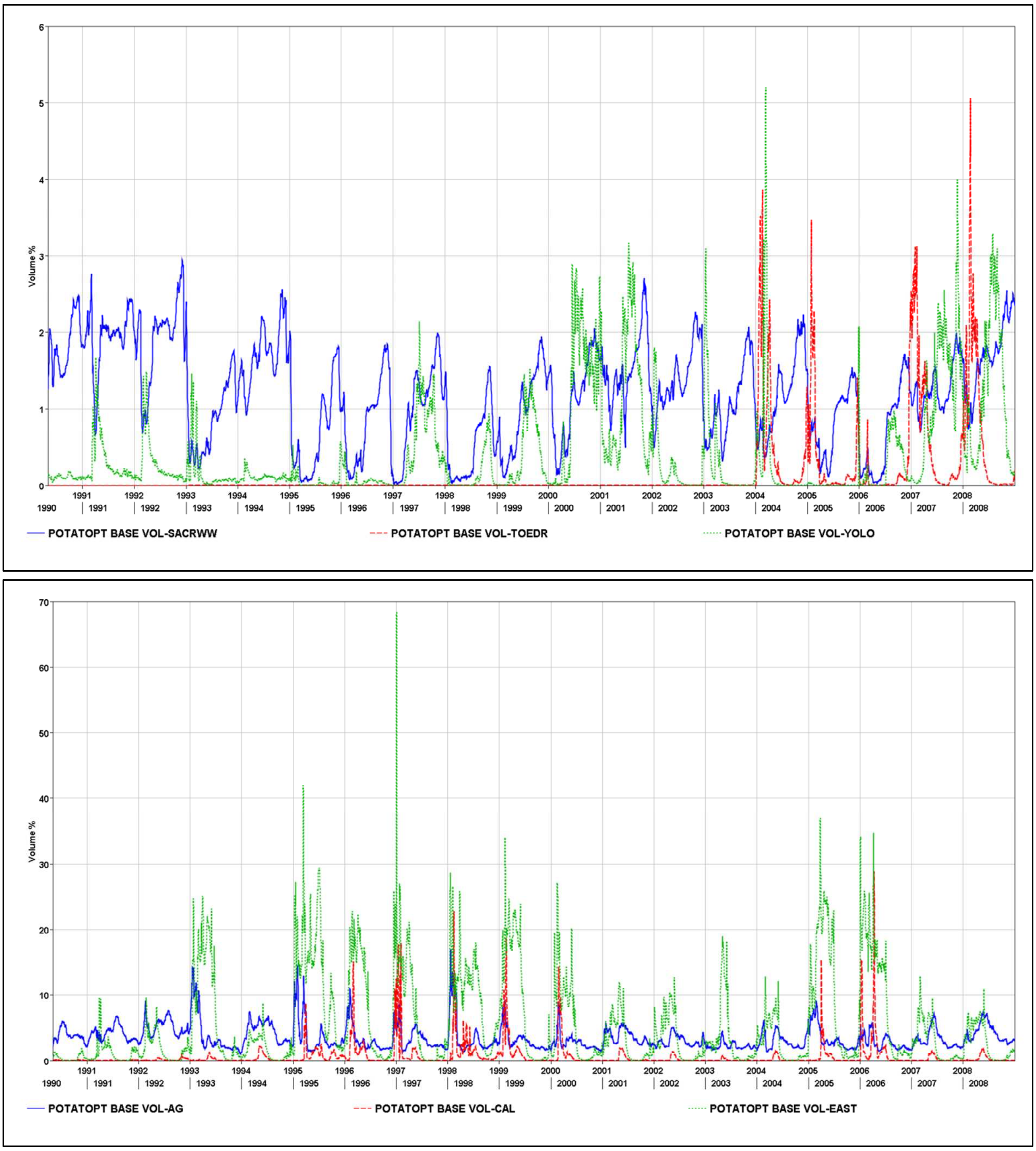


Figure 17-80 Sac Regional effluent volumes remain high at Potato Point, although Ag contributions are higher here.

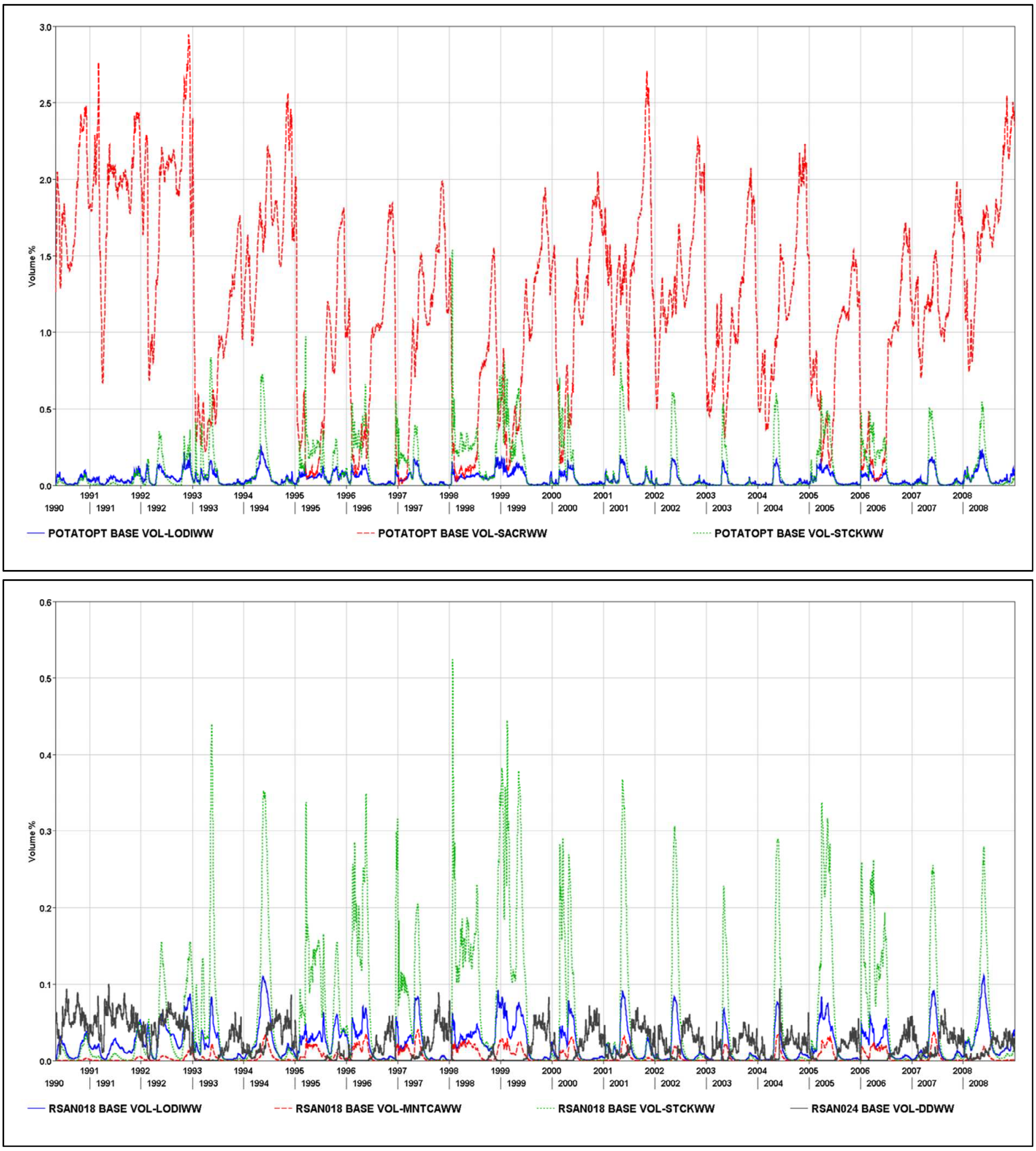


Figure 17-81 Contributions from smaller WWTPs in the lower San Joaquin River.

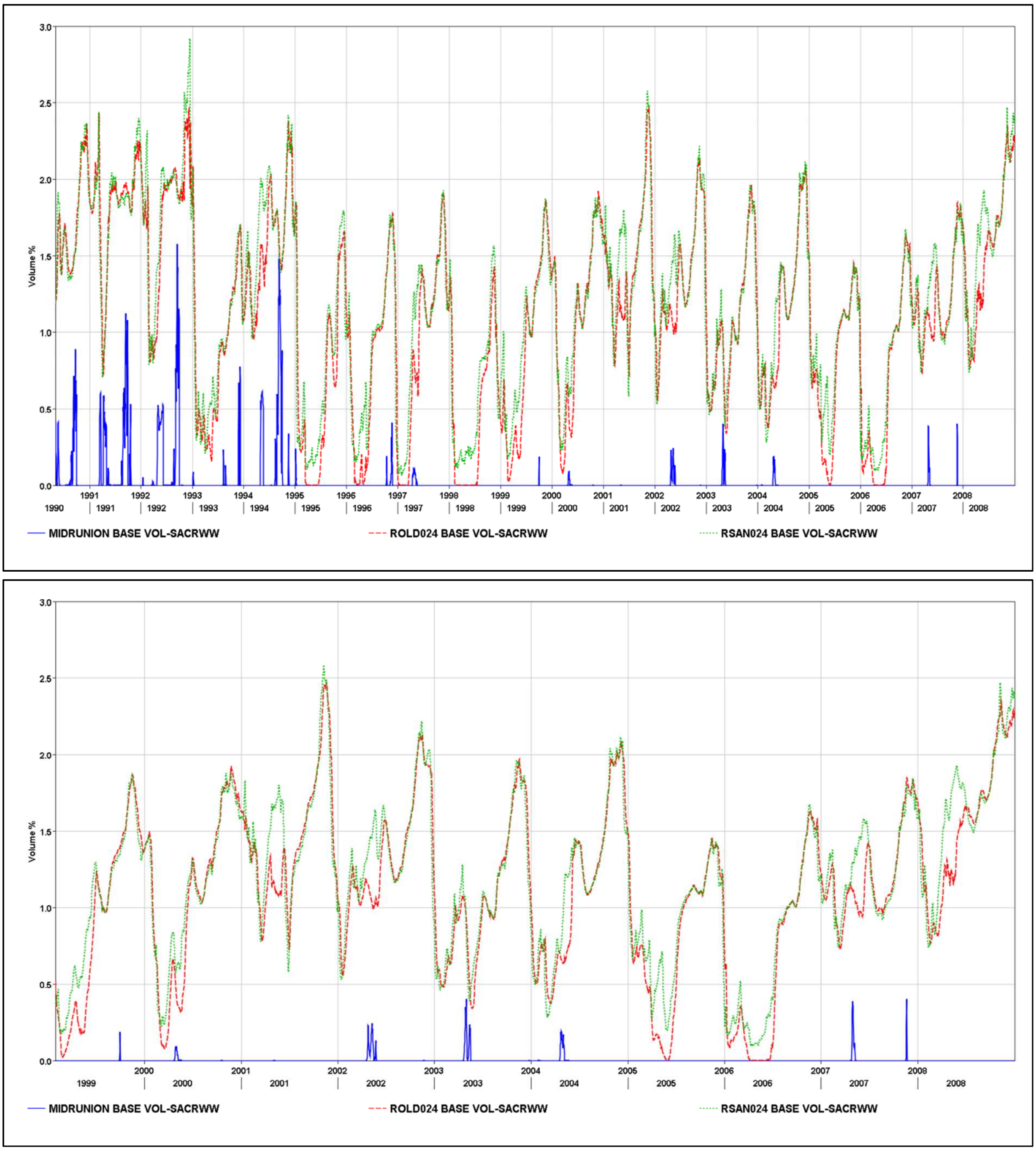


Figure 17-82 Sac Regional effluent contributions are small in the south Delta.

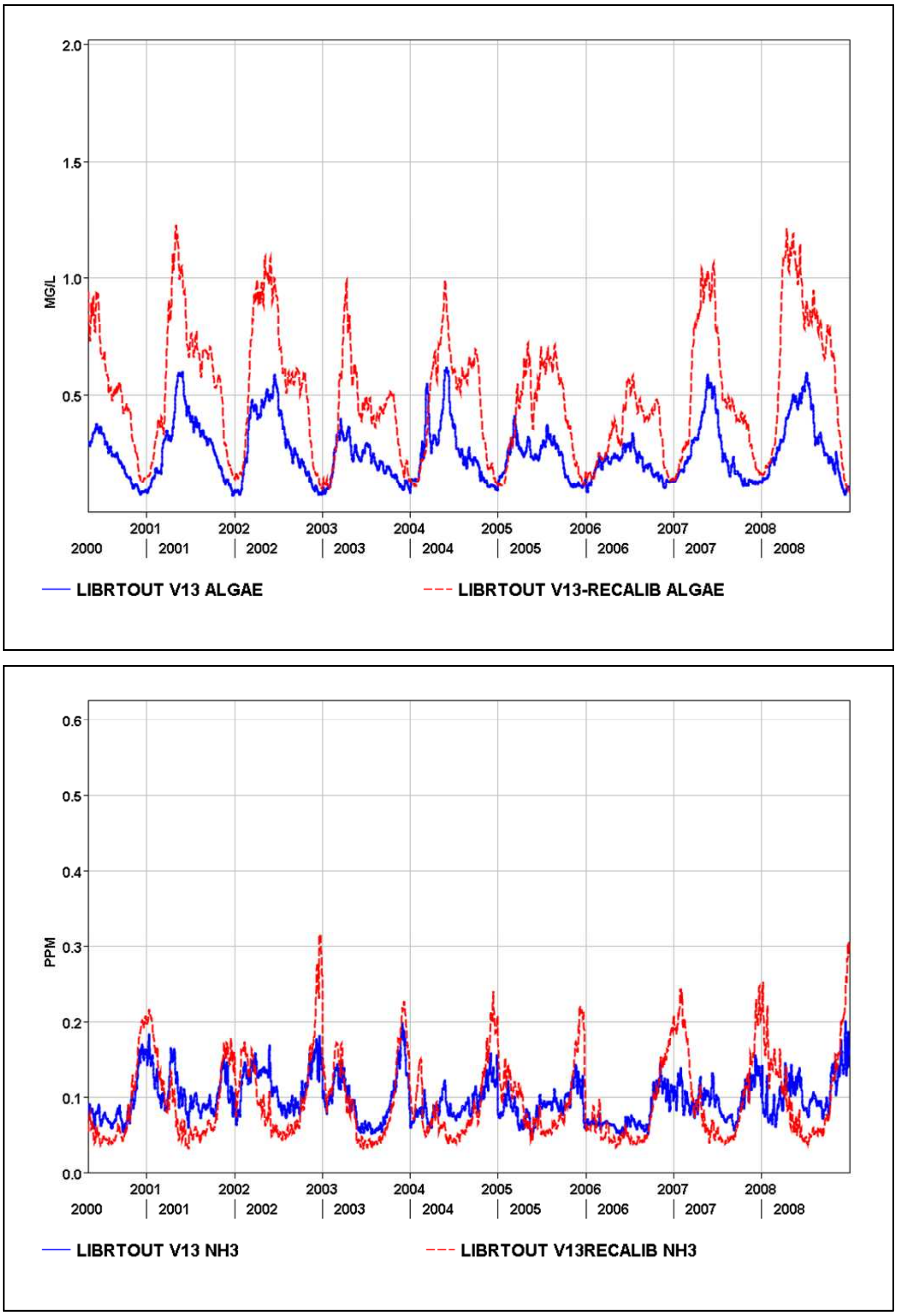
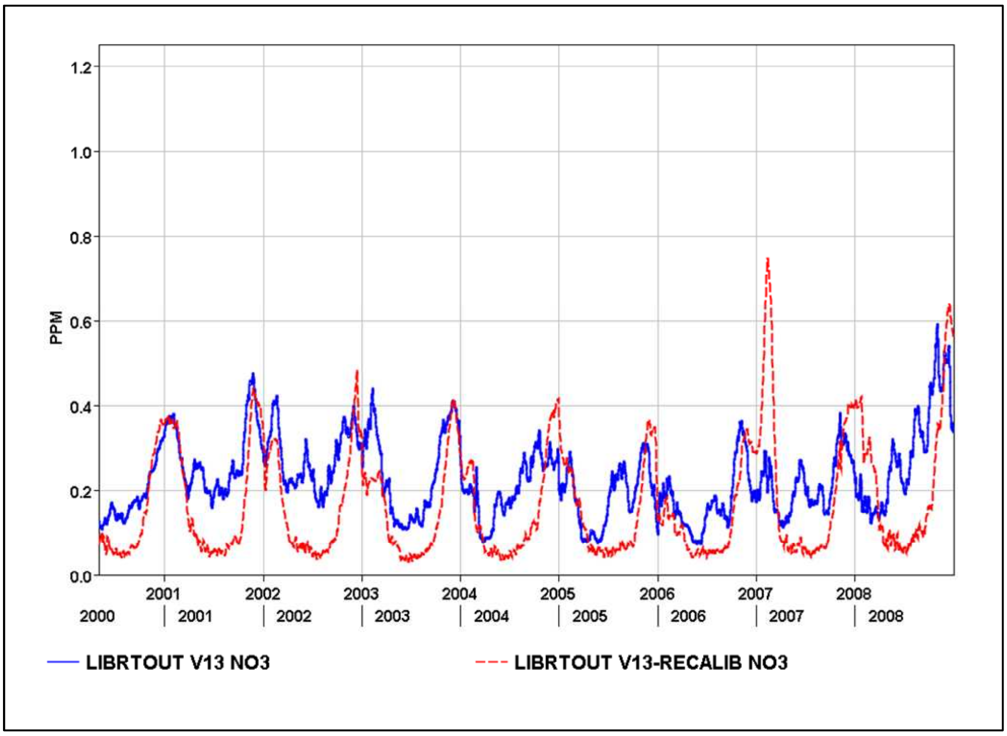


Figure 17-83 Algal biomass and ammonia concentrations at the Liberty location for Base and Liberty grids.



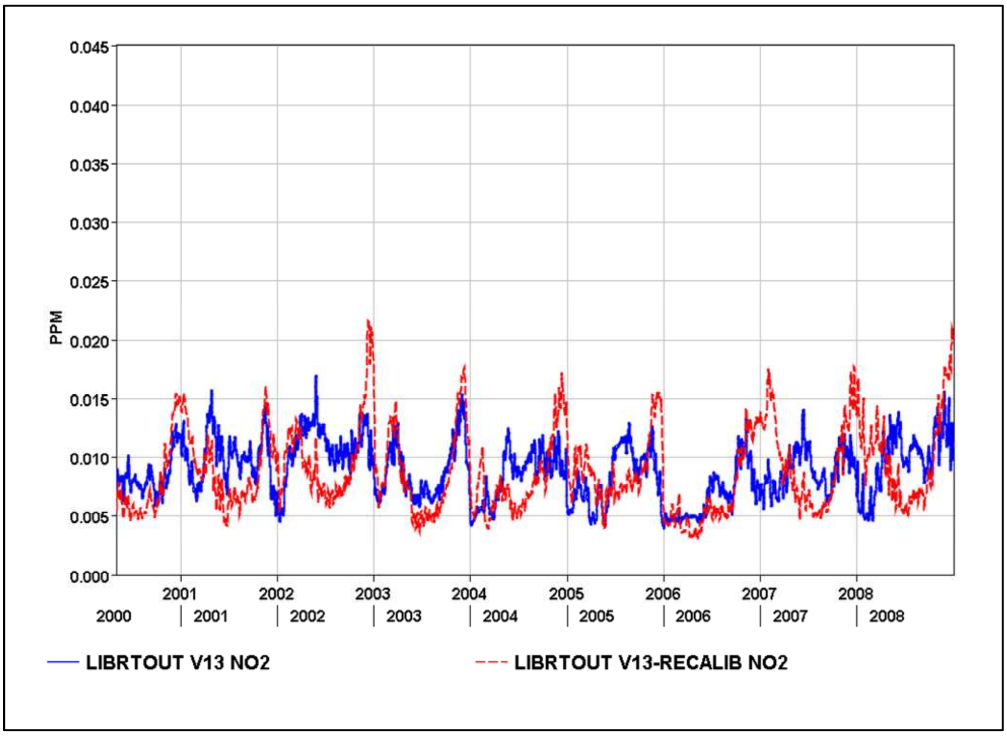


Figure 17-84 Nitrate and nitrite concentrations at the Liberty location for Base and Liberty grids.

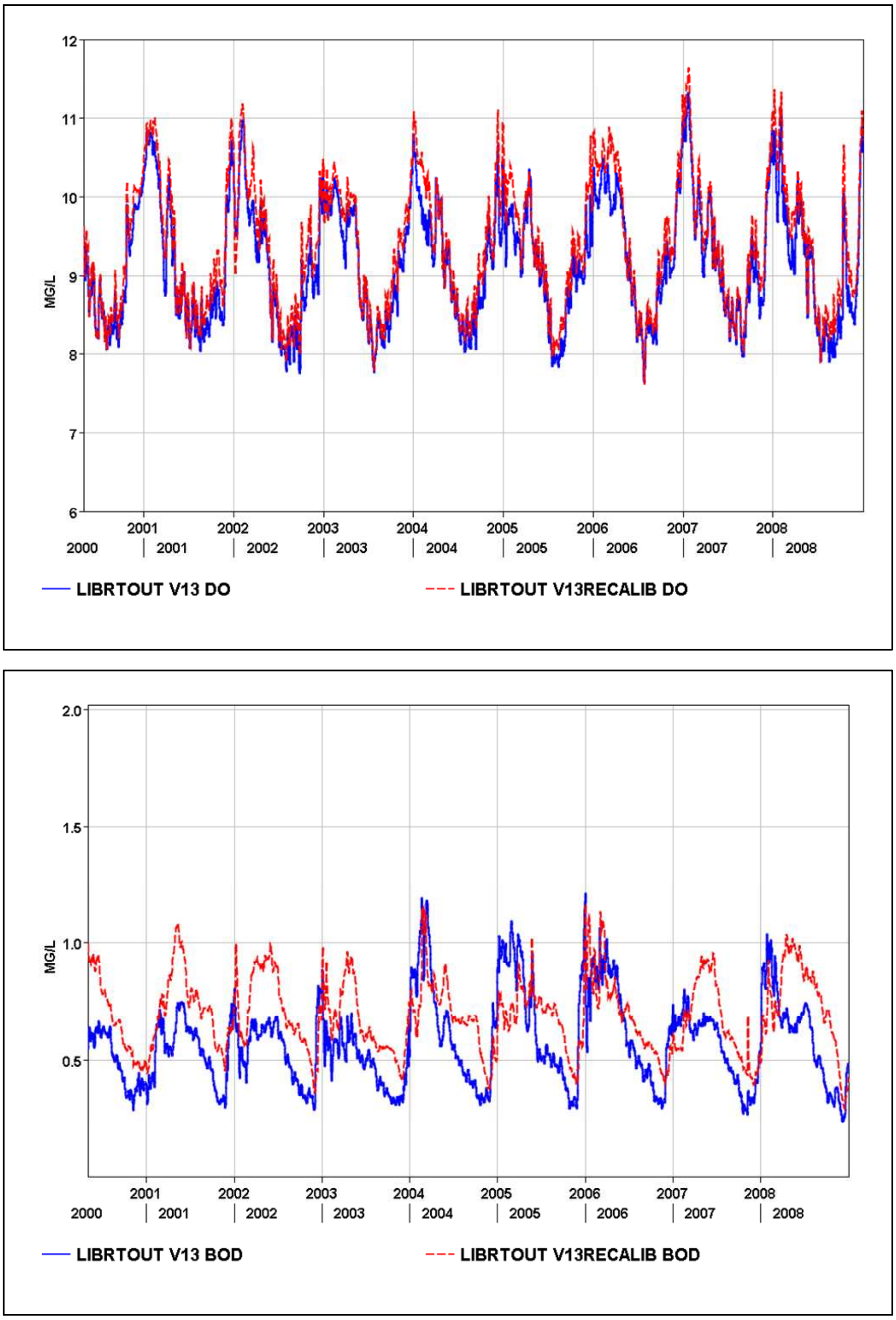
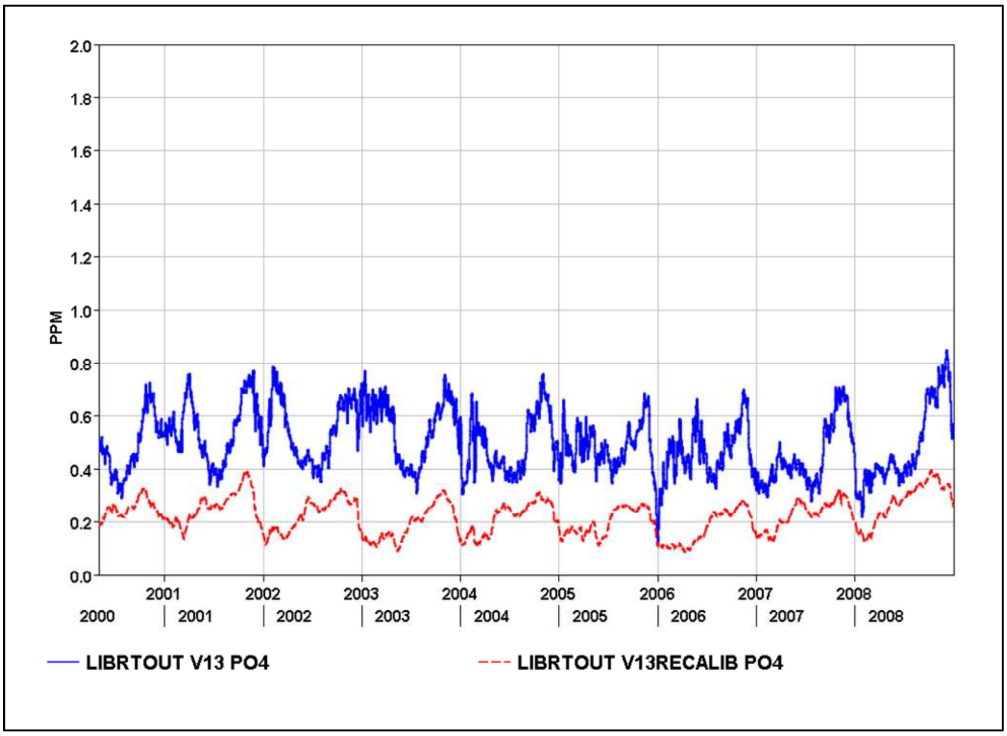


Figure 17-85 DO and CBOD concentrations at the Liberty location for Base and Liberty grids.



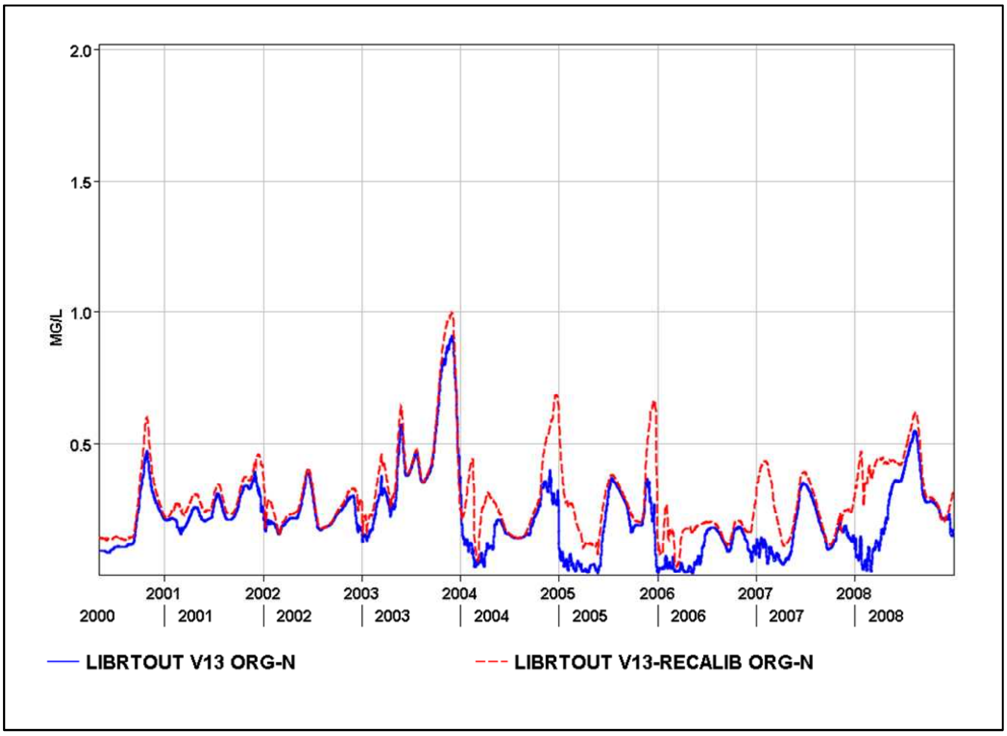
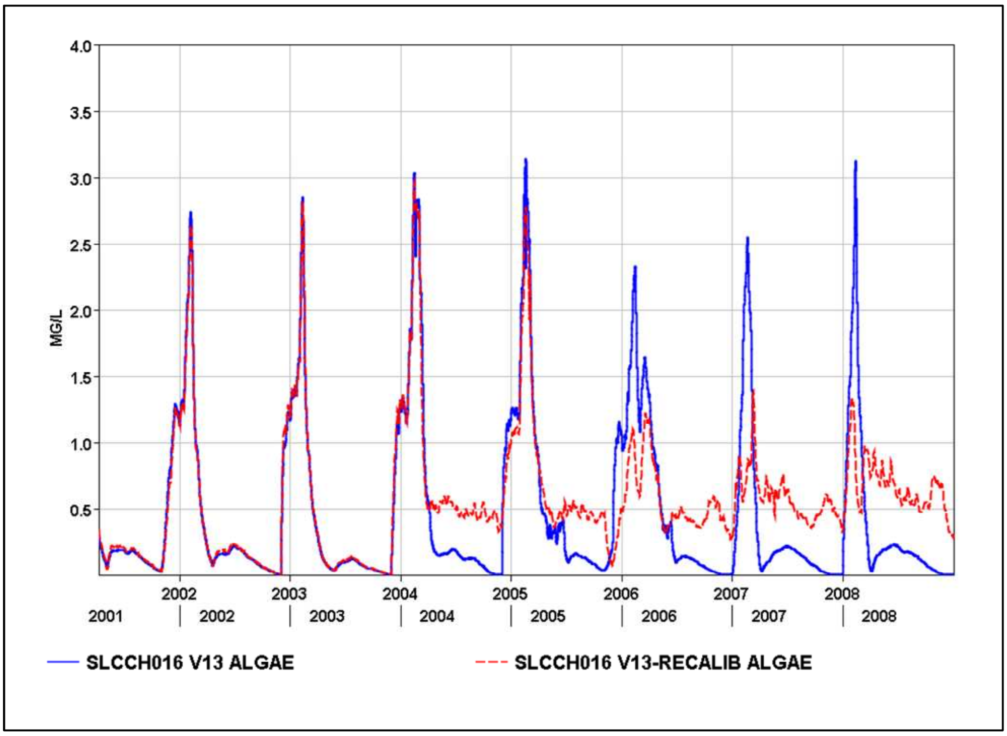


Figure 17-86 PO_4 and organic-N concentrations at the Liberty location for Base and Liberty grids.



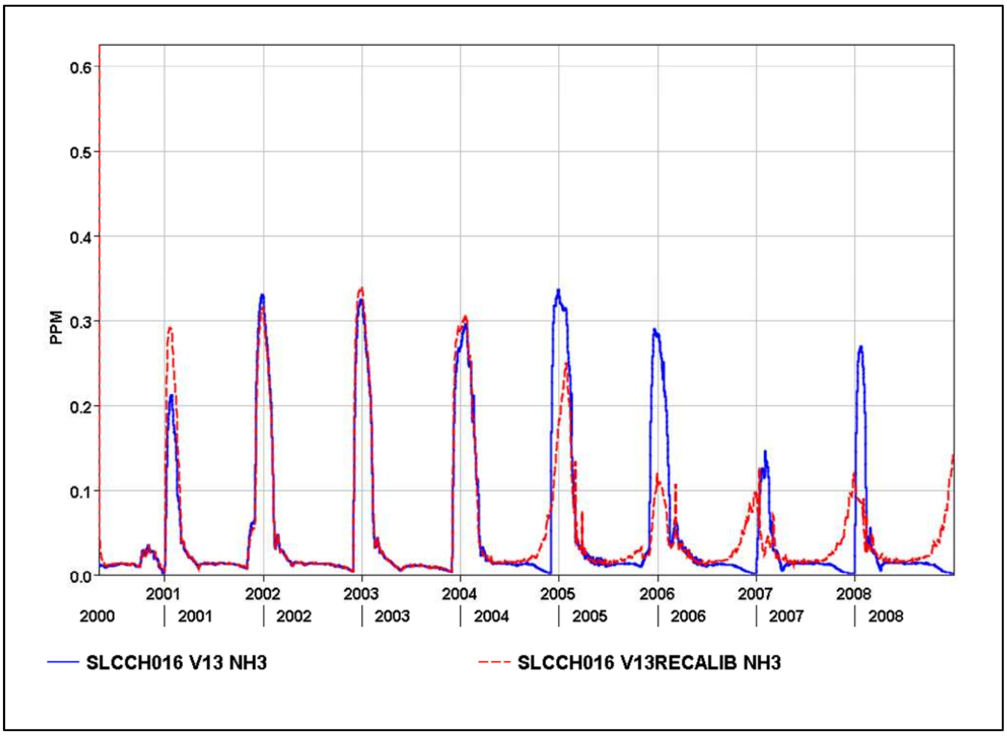


Figure 17-87 Algal biomass and ammonia concentrations at SLCCH016 for Base and Liberty grids.

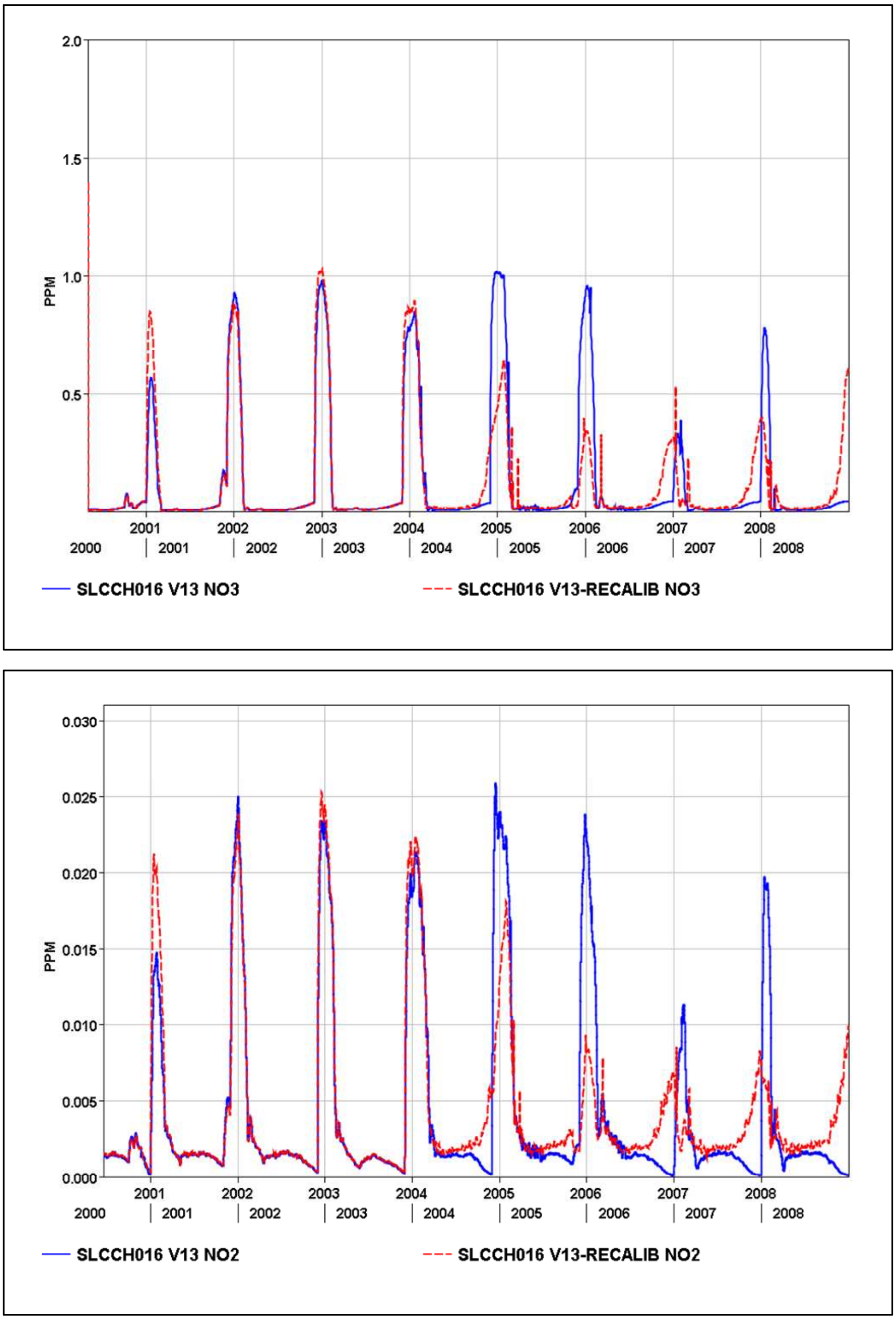
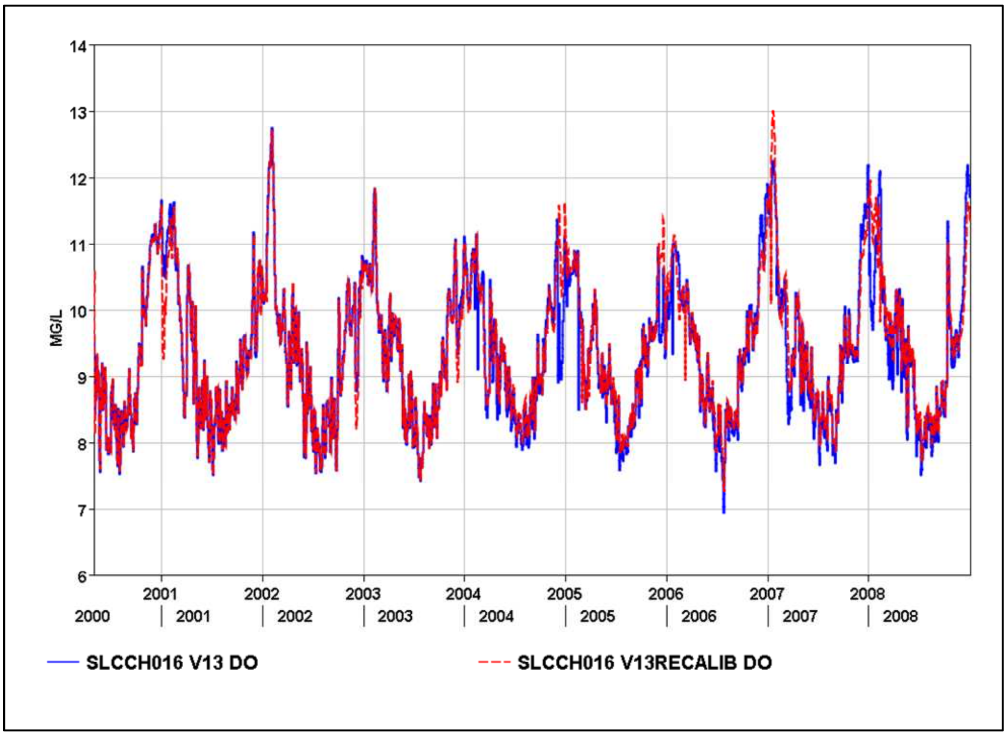


Figure 17-88 Nitrate and nitrite concentrations at SLCCH016 for Base and Liberty grids.



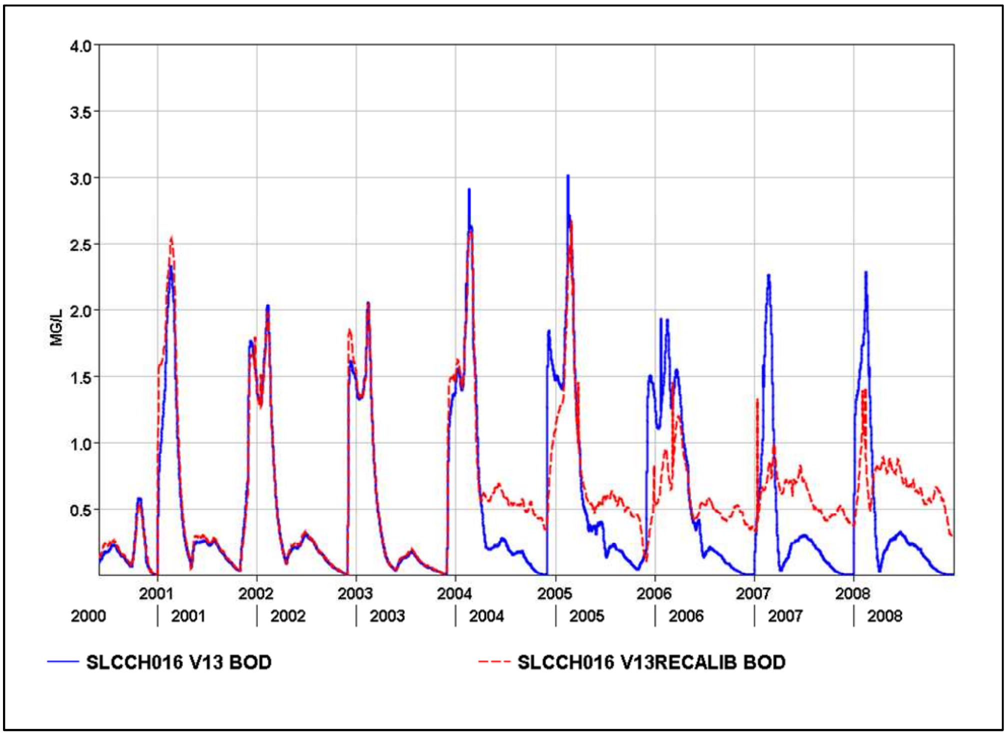
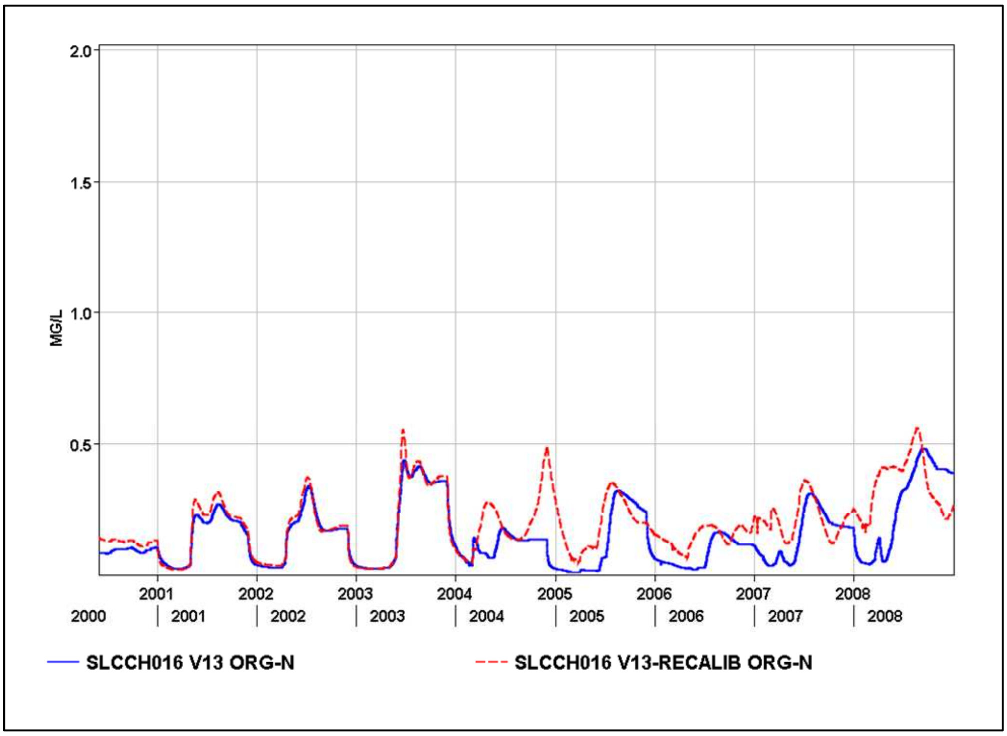


Figure 17-89 DO and CBOD concentrations at SLCCH016 for Base and Liberty grids.



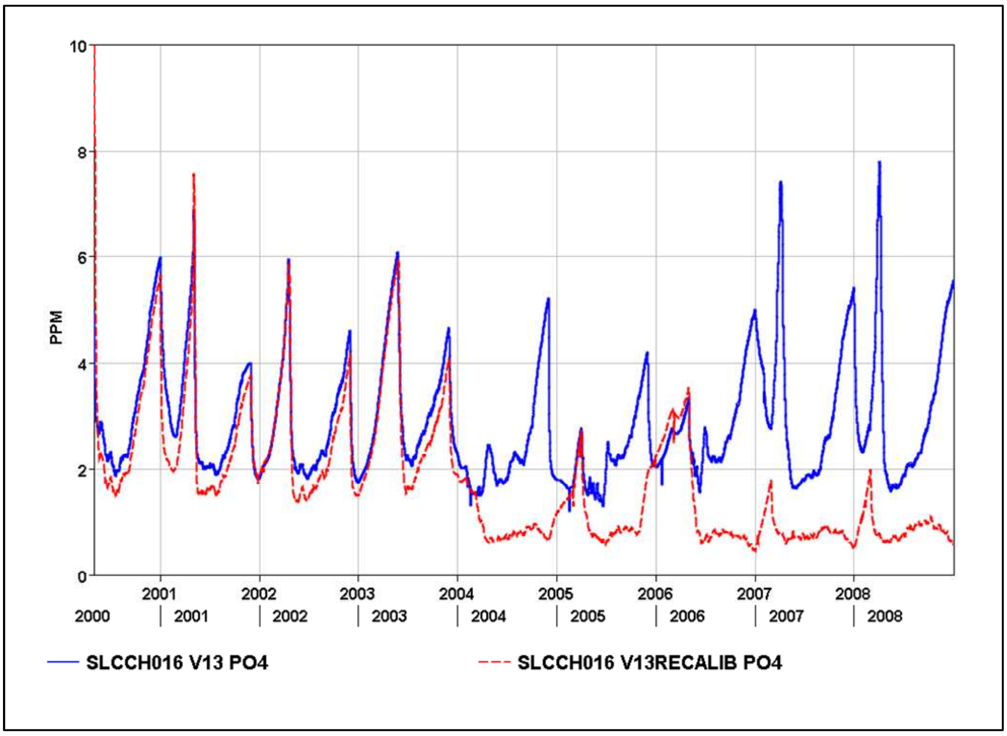


Figure 17-90Organic-N and PO_4 concentrations at SLCCH016 for Base and Liberty grids.

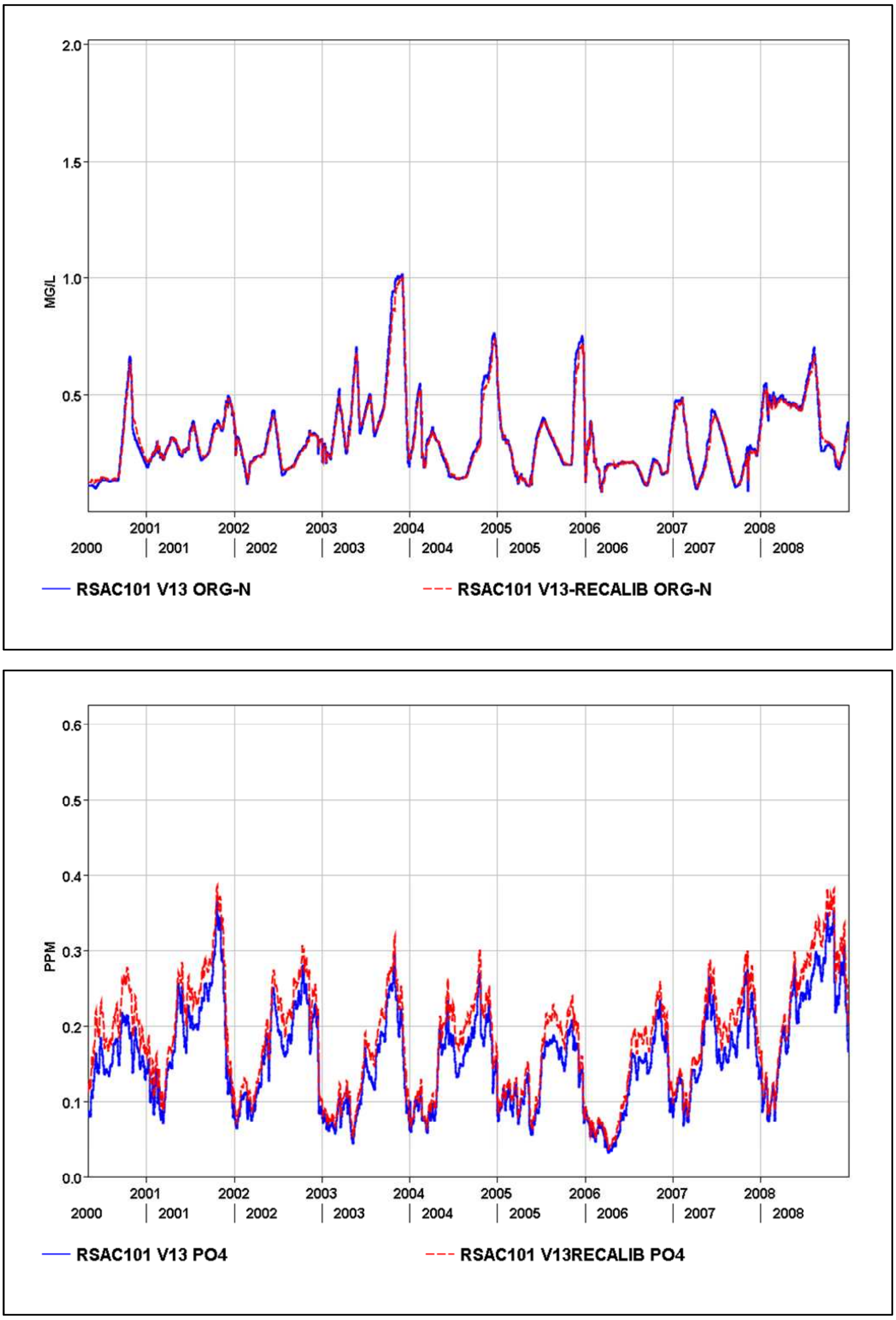
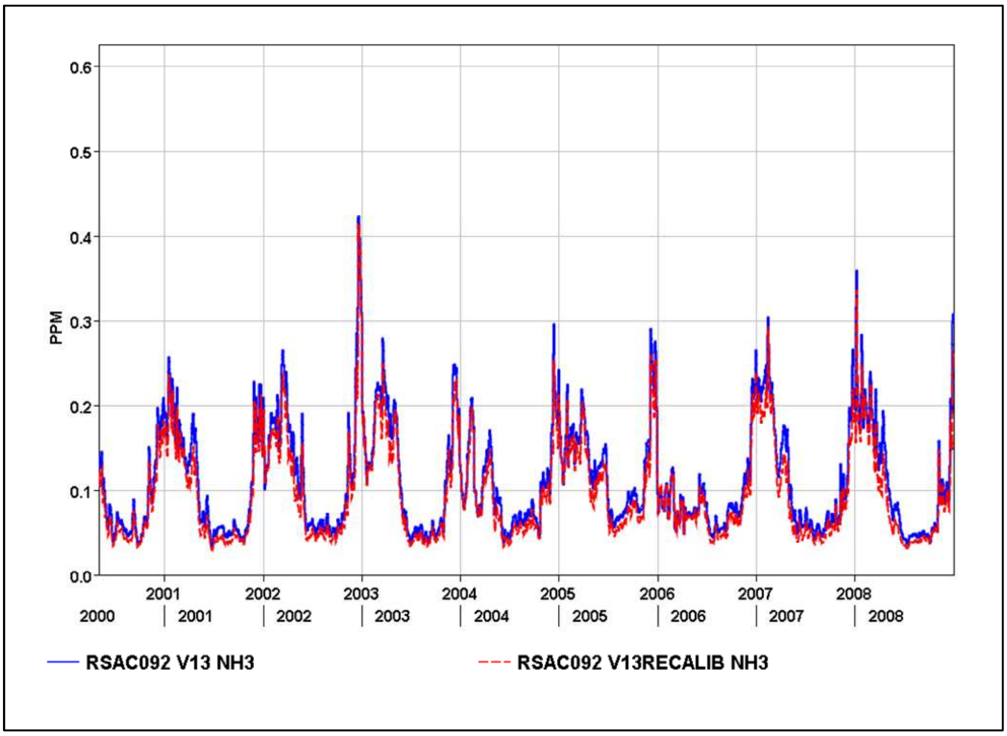


Figure 17-91 Organic-N and PO_4 concentration at RSAC101 for Base and Liberty grids.



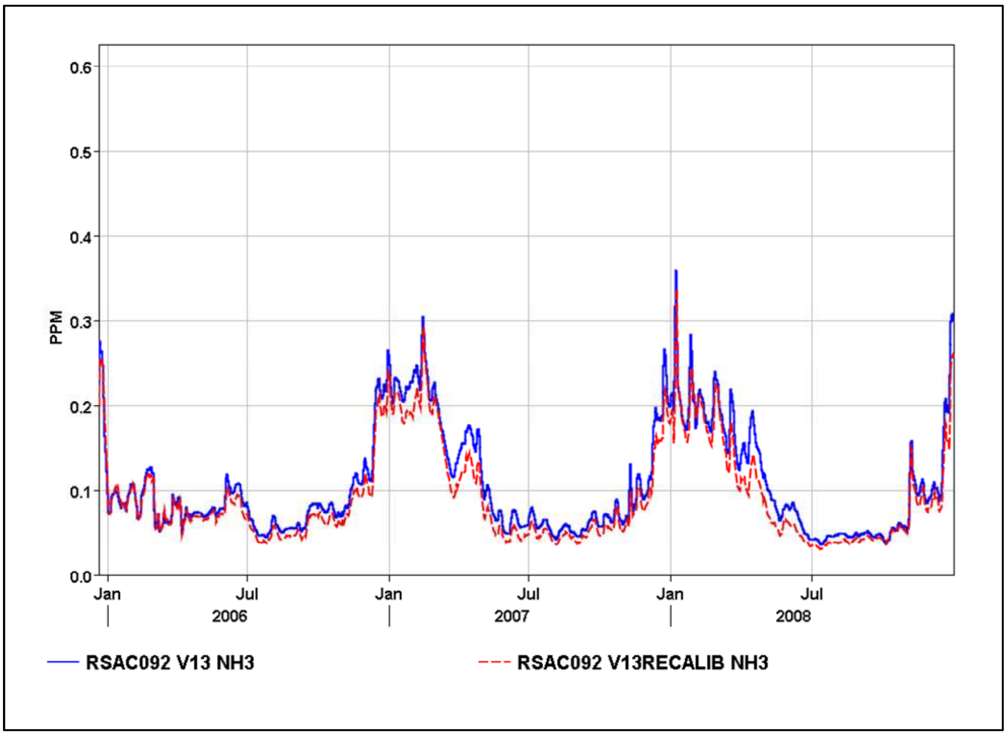
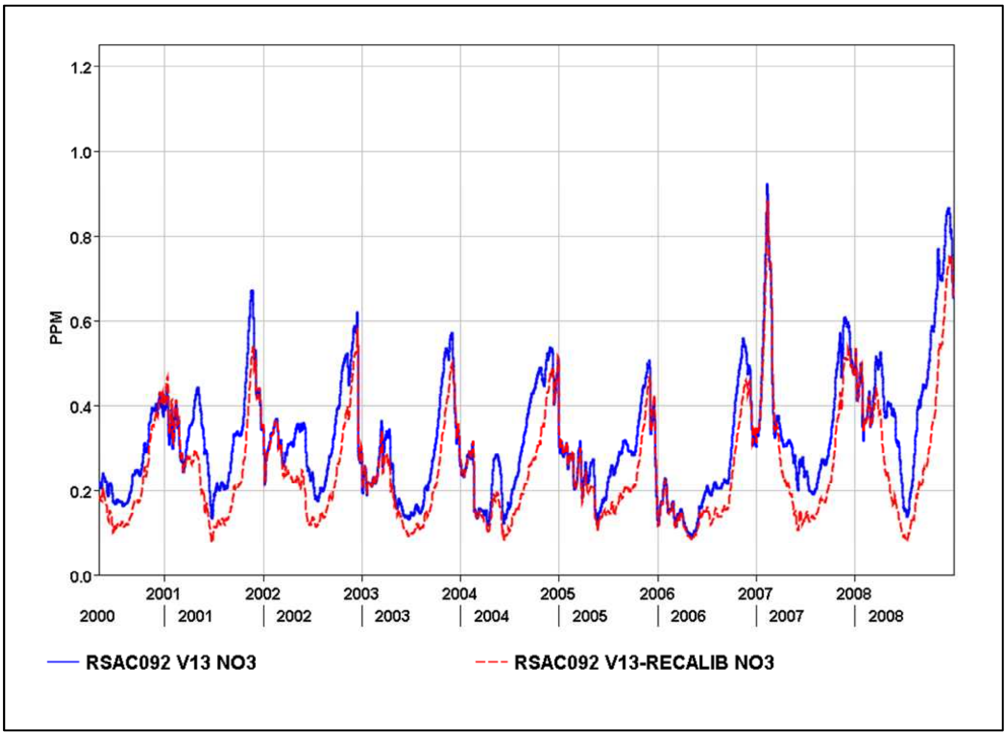


Figure 17-92 Ammonia concentration at RSAC092 for Base and Liberty grids.



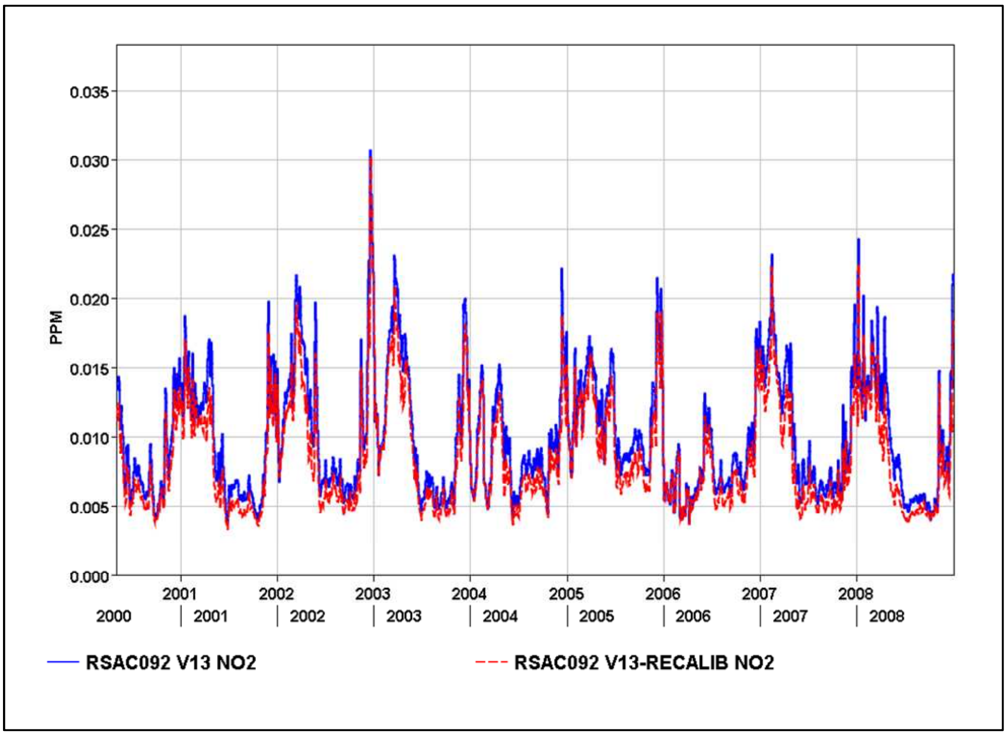
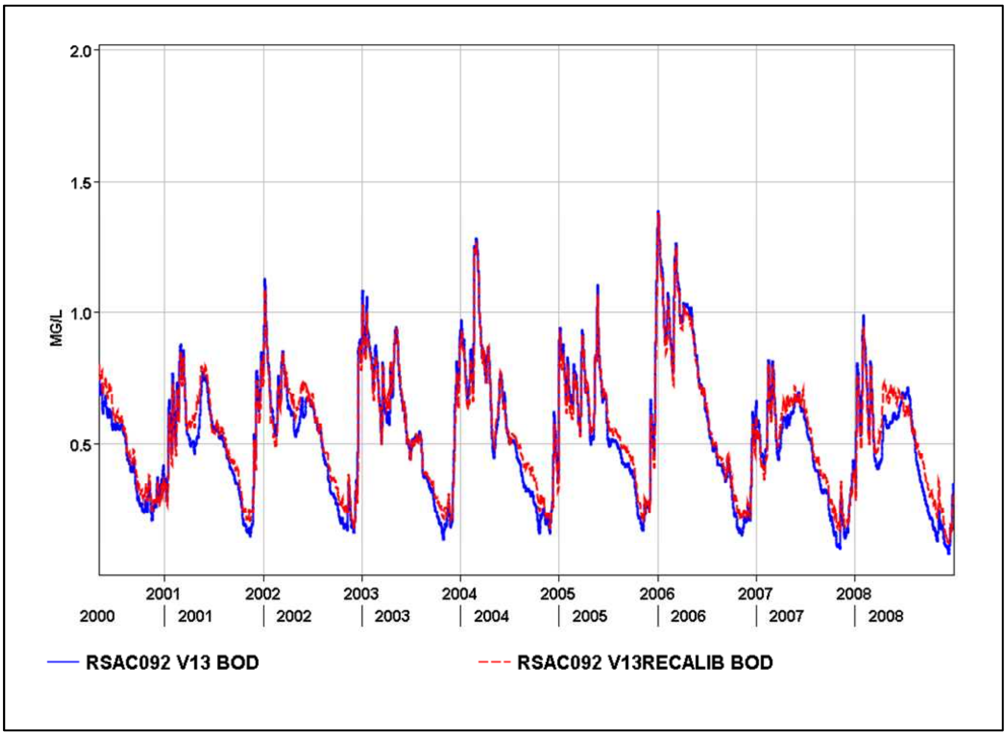


Figure 17-93 Nitrate and nitrite concentrations at RSAC092 for Base and Liberty grids.



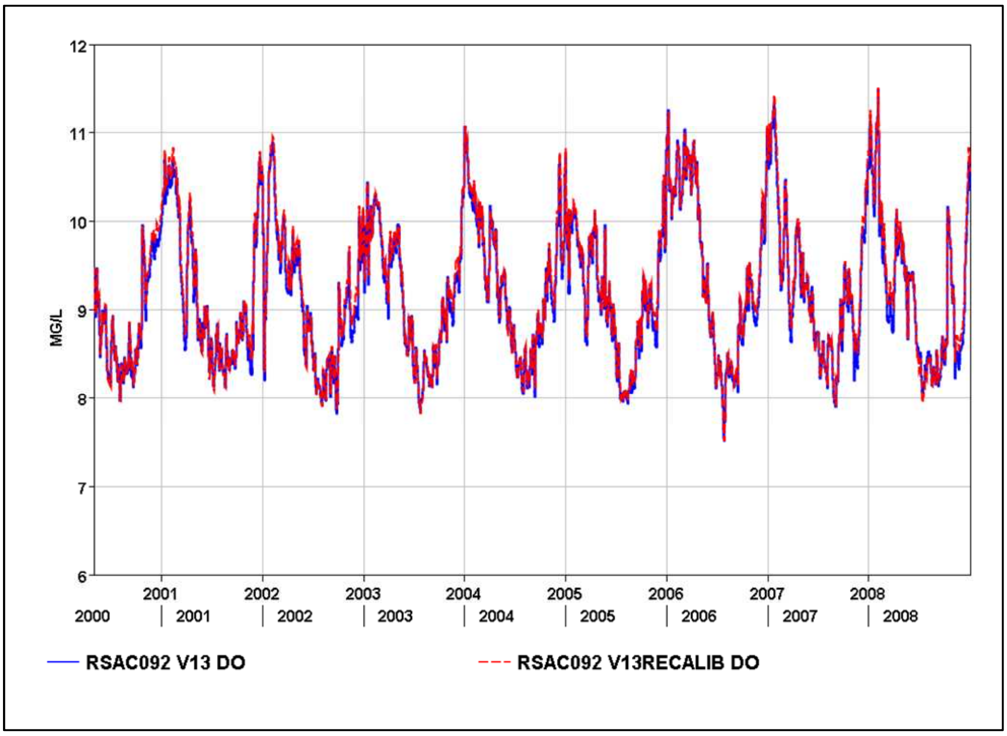
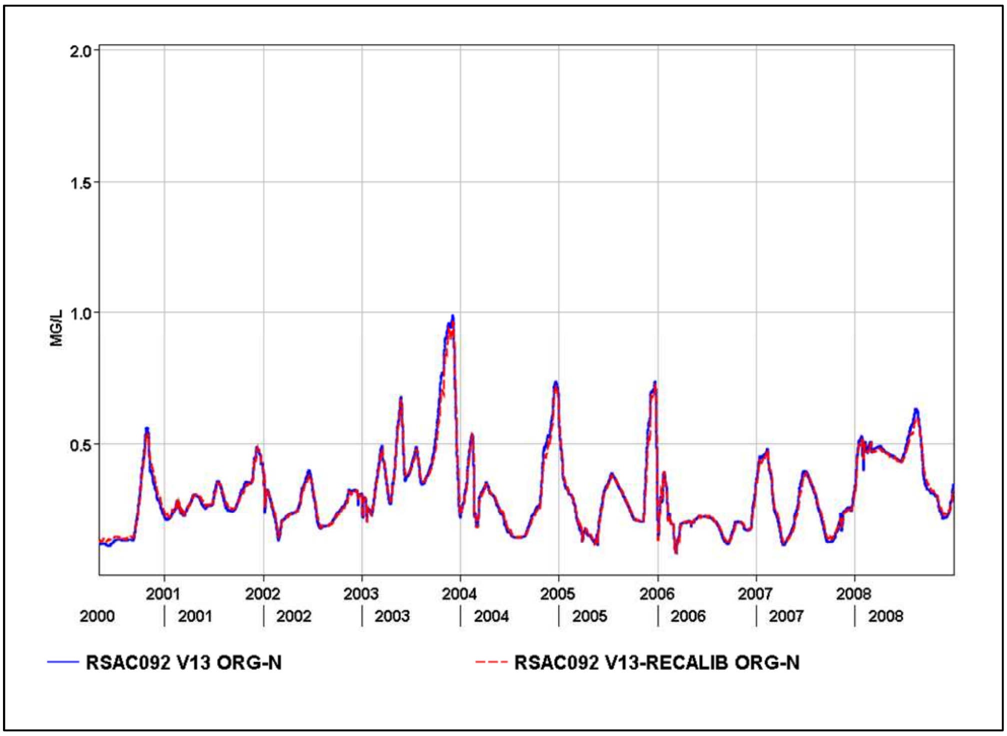


Figure 17-94 CBOD and DO concentrations at RSAC092 for Base and Liberty grids.



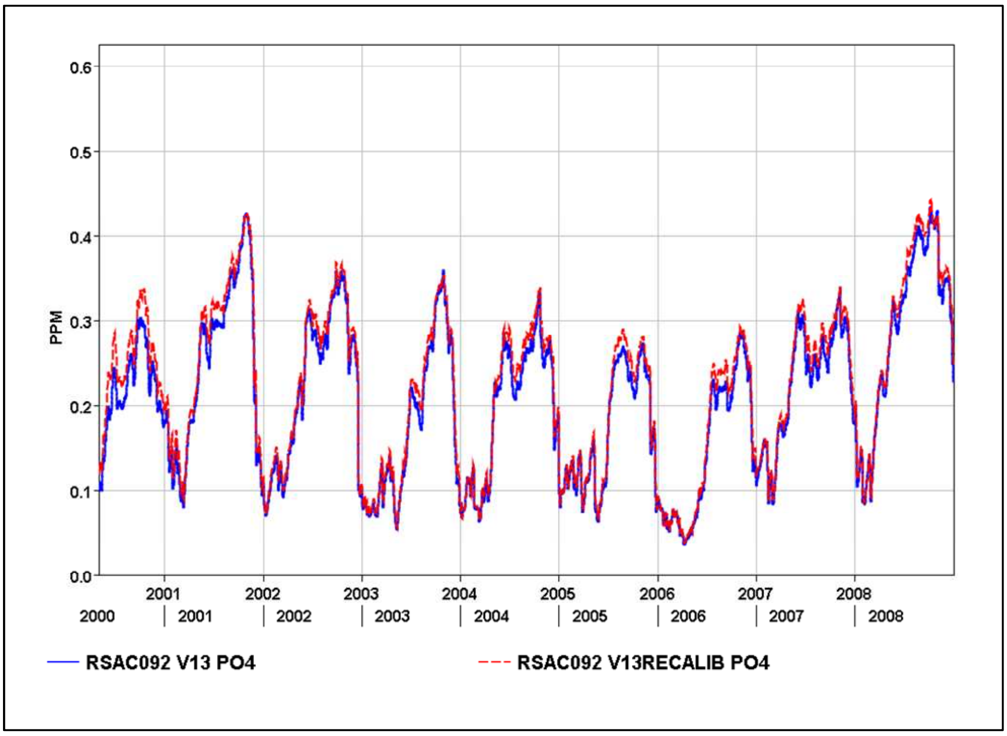
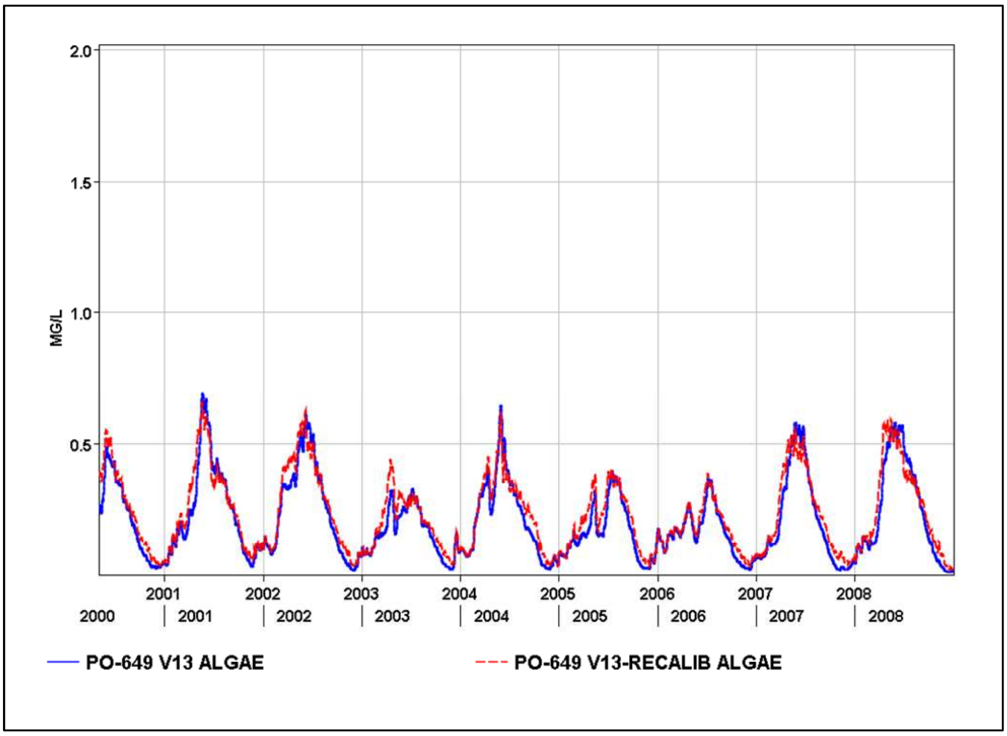


Figure 17-95 Organic-N and PO_4 concentrations at RSAC092 for Base and Liberty grids.



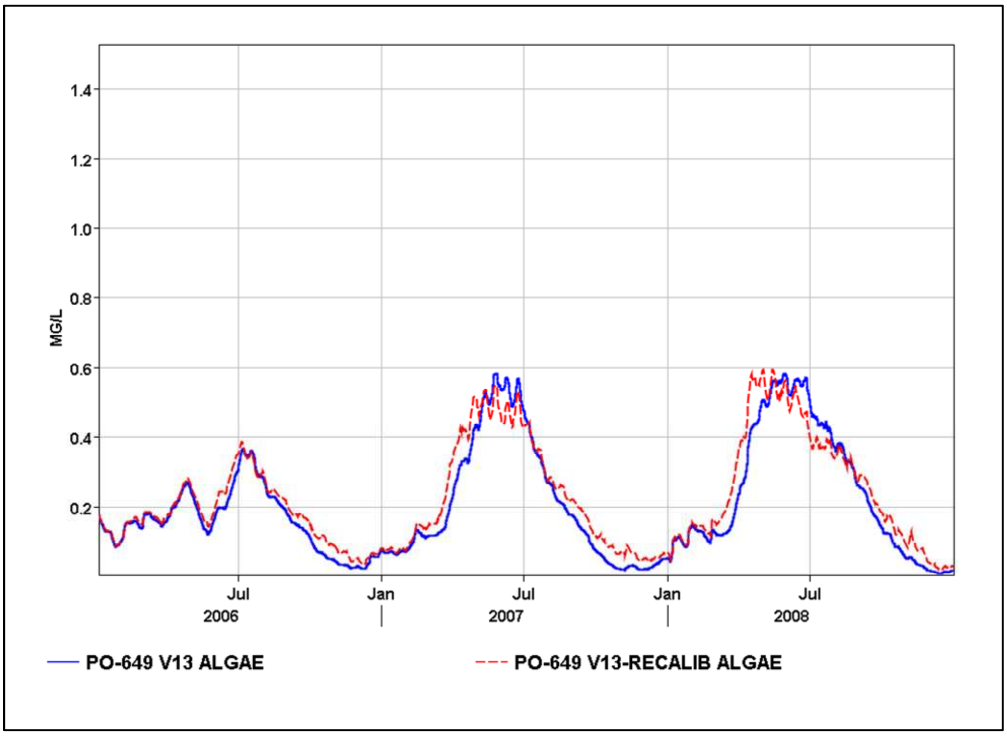


Figure 17-96 Algal biomass Point Sacramento for Base and Liberty grids.

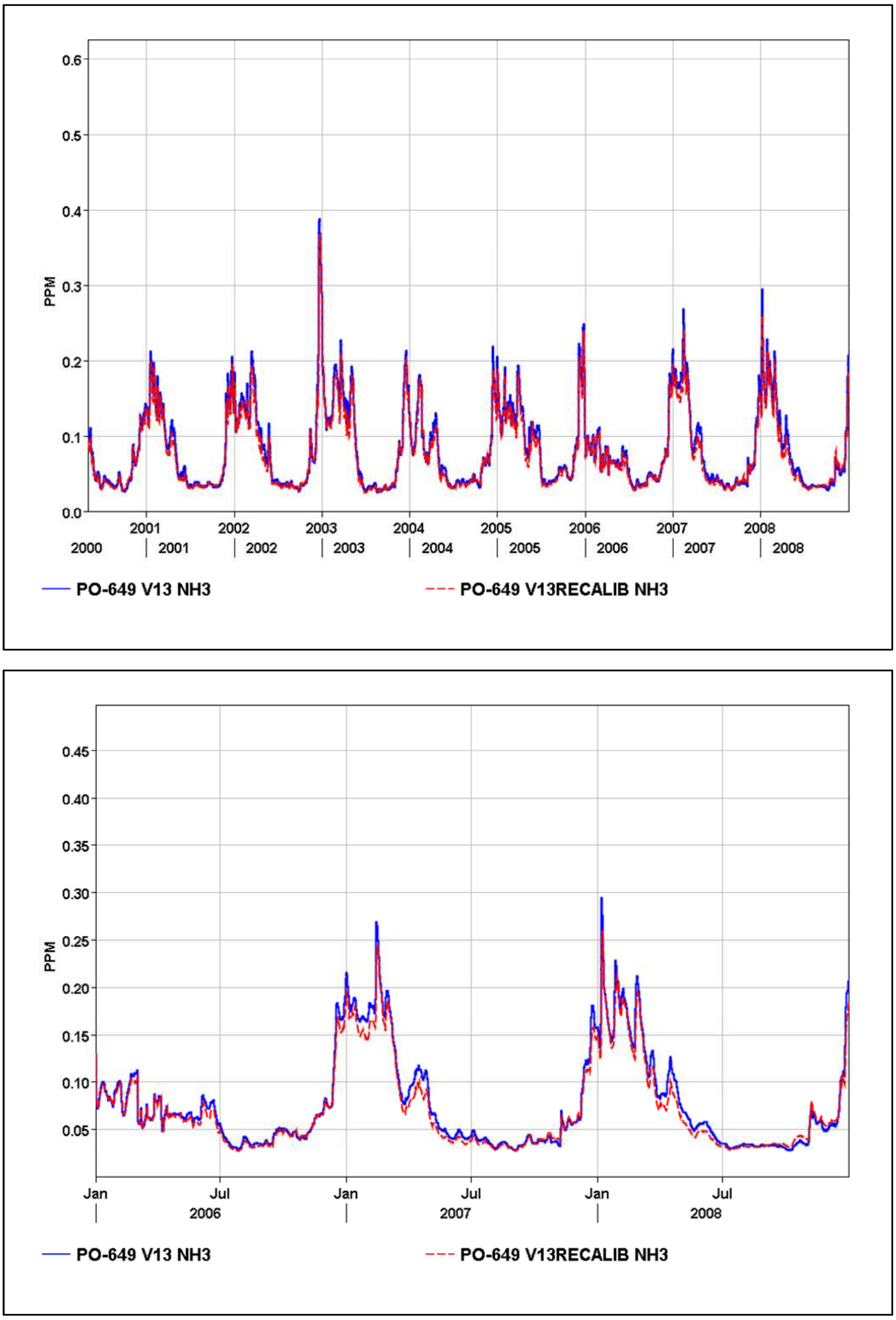
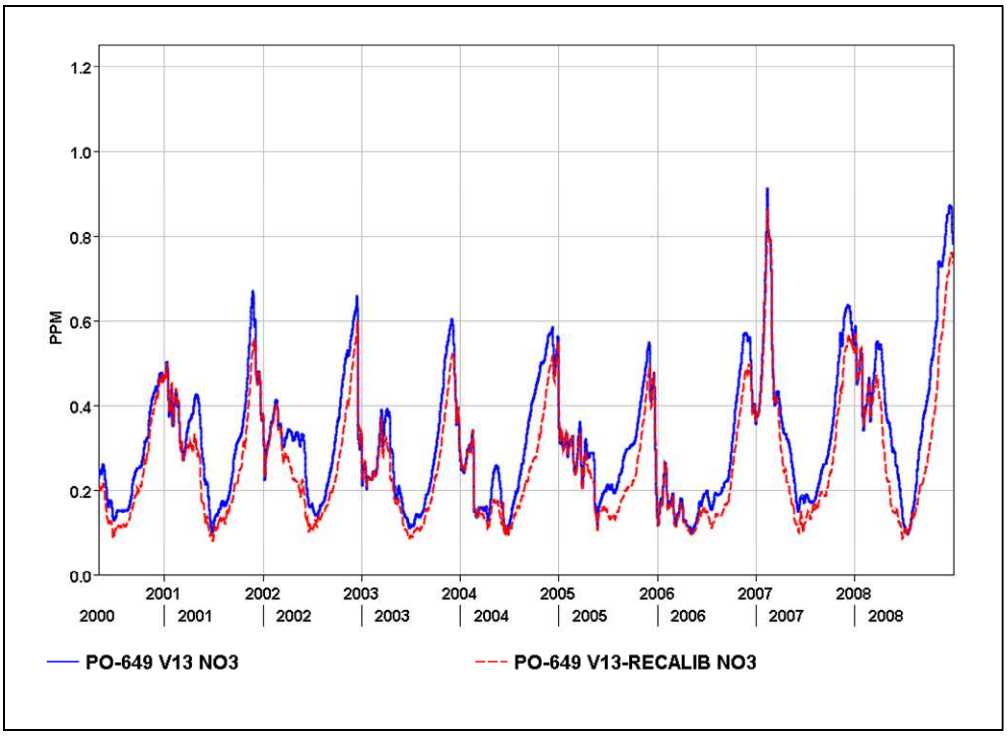


Figure 17-97 Ammonia concentration at Point Sacramento for Base and Liberty grids.



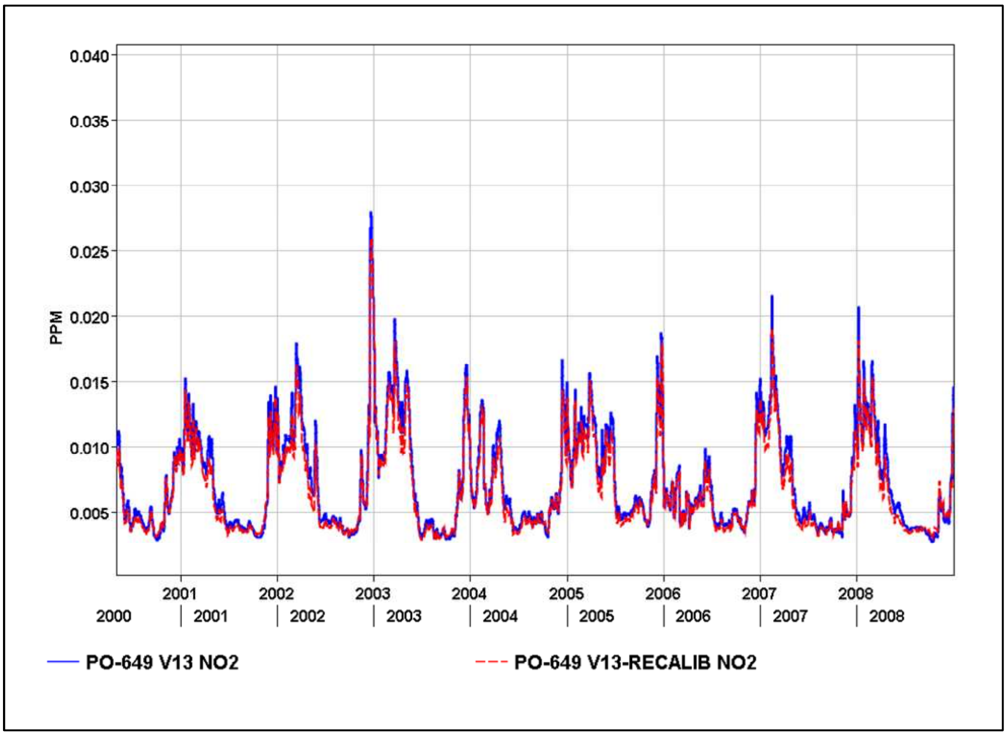


Figure 17-98 Nitrate and nitrite concentrations at Point Sacramento for Base and Liberty grids.

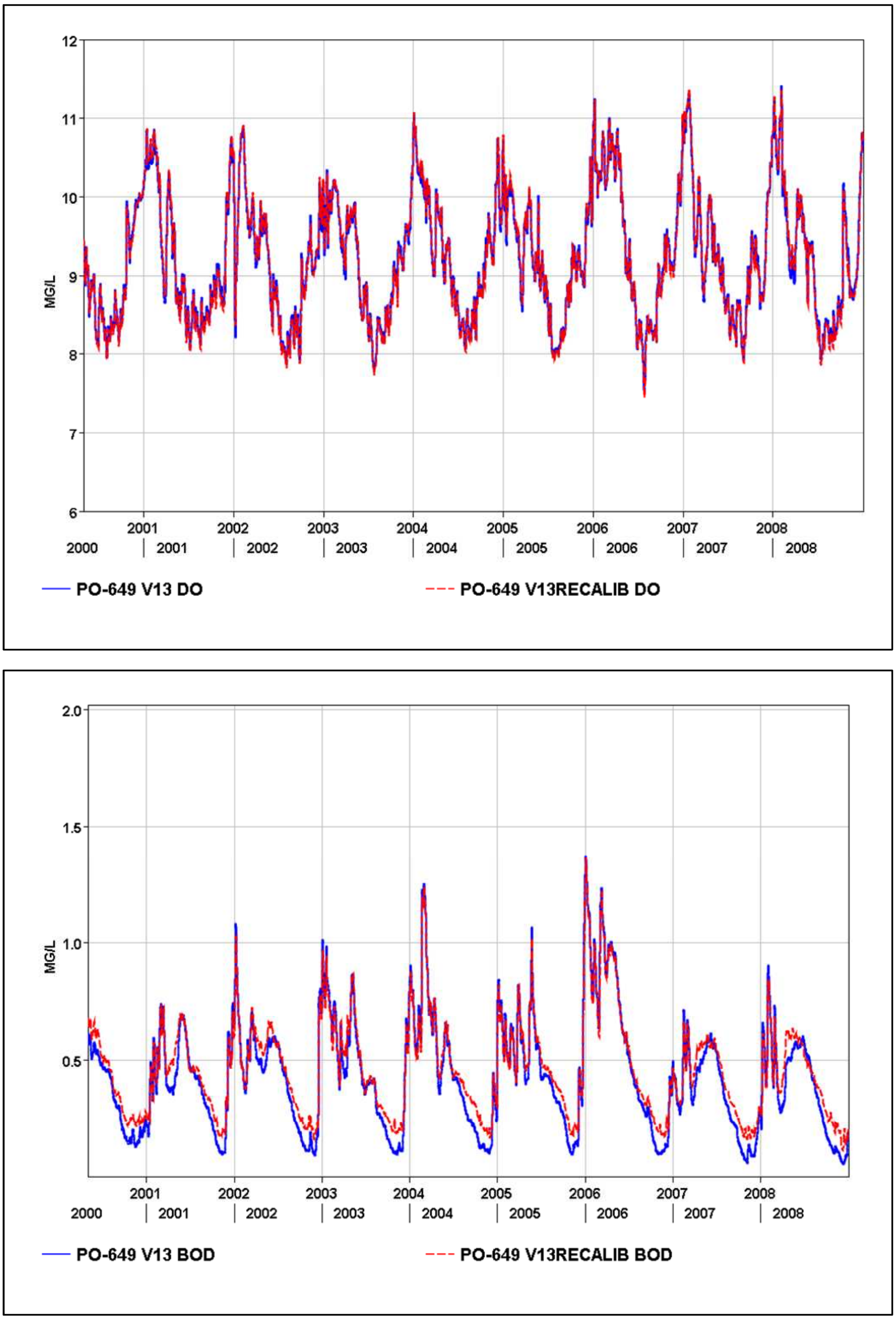
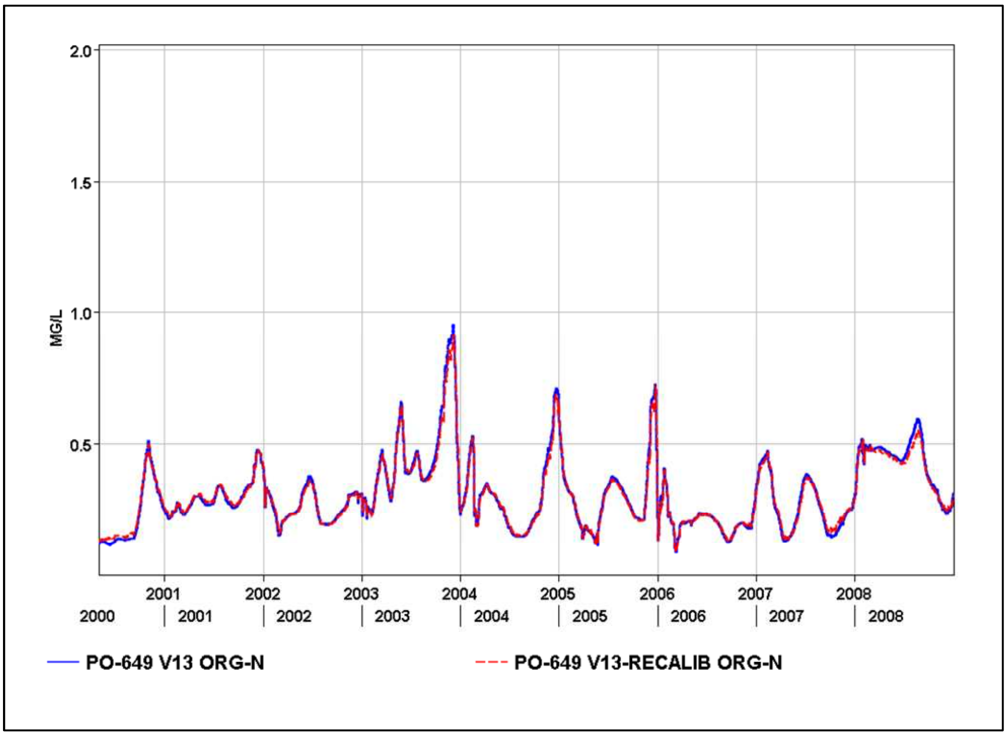


Figure 17-99 DO and CBOD concentrations at Point Sacramento for Base and Liberty grids.



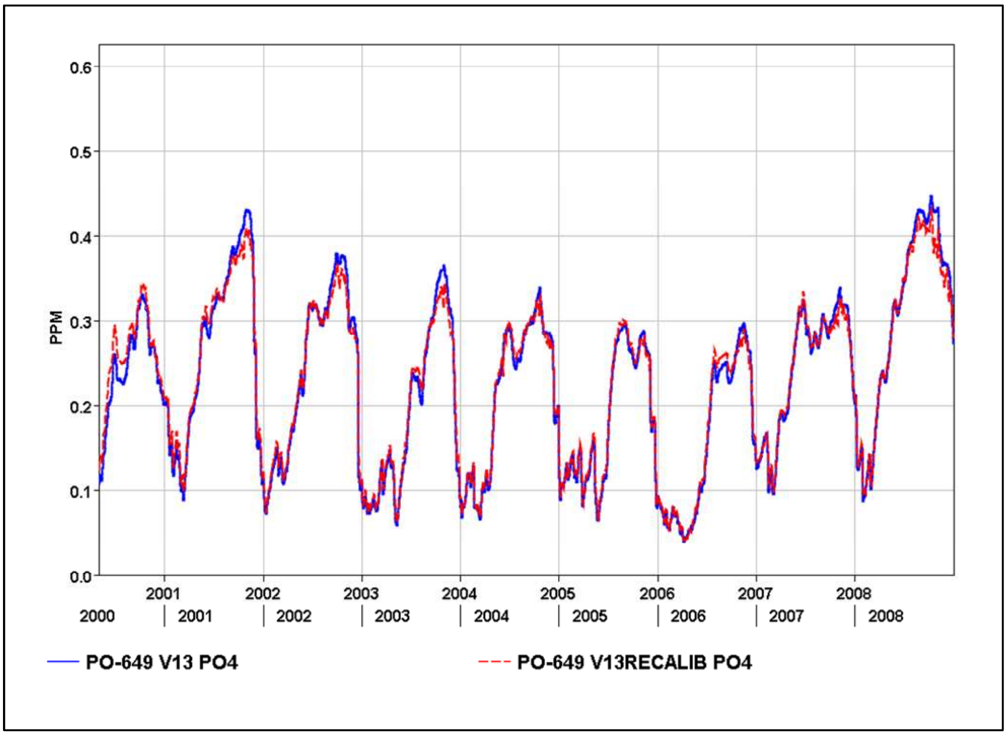
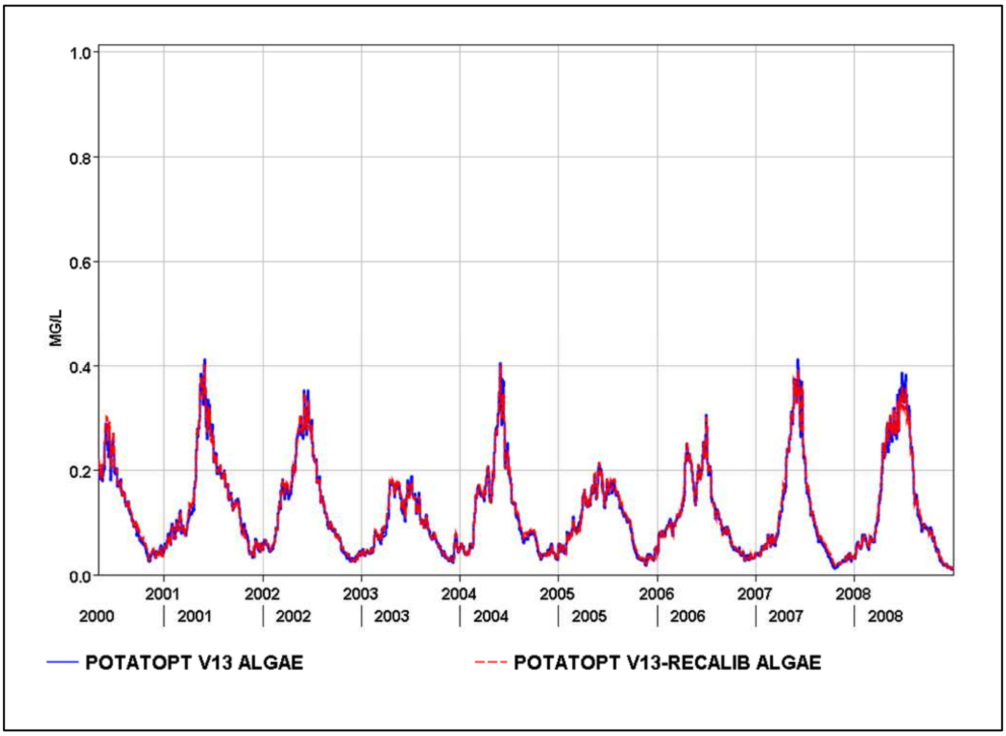


Figure 17-100 Organic-N and PO4 concentrations at Point Sacramento for Base and Liberty grids.



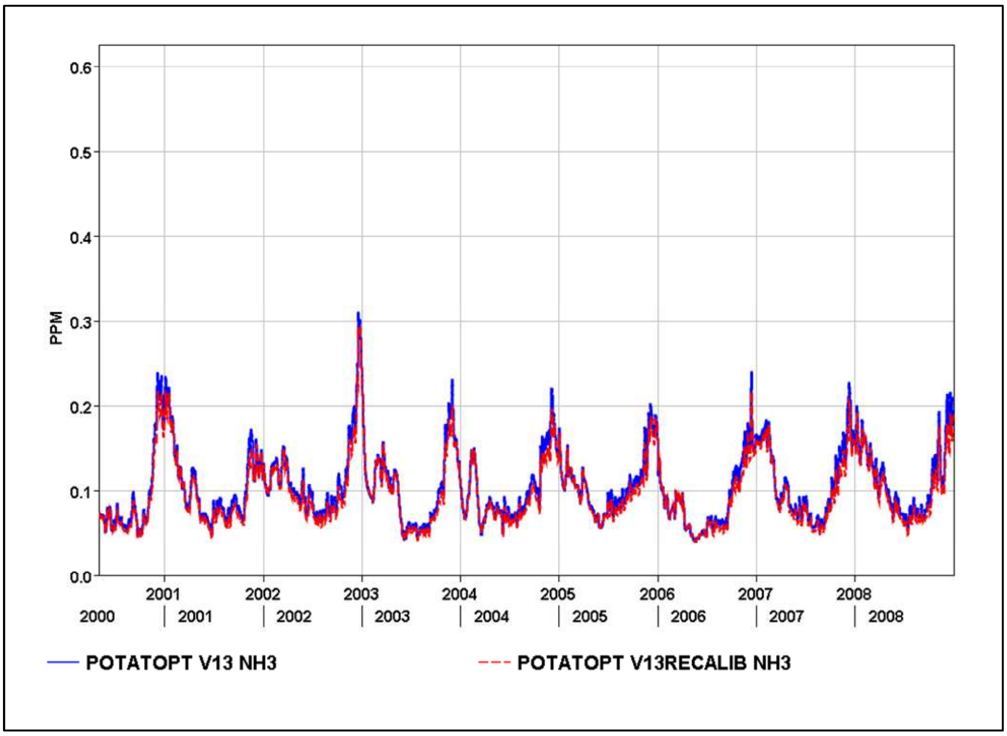
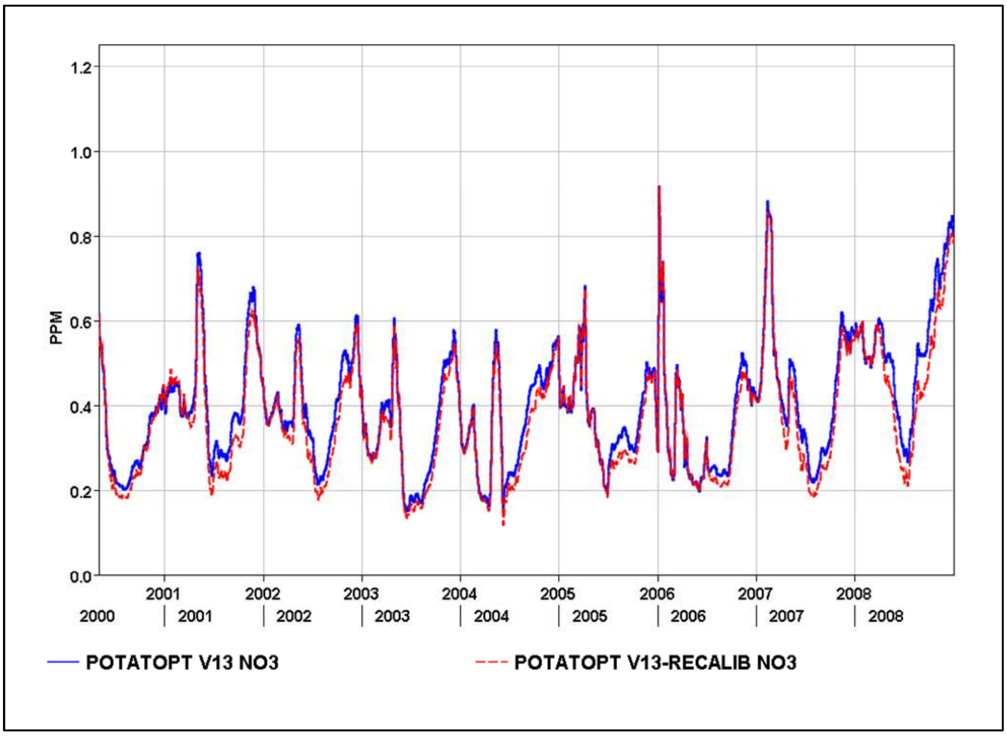


Figure 17-101 Algal biomass and ammonia concentrations at Potato Point for Base and Liberty grids.



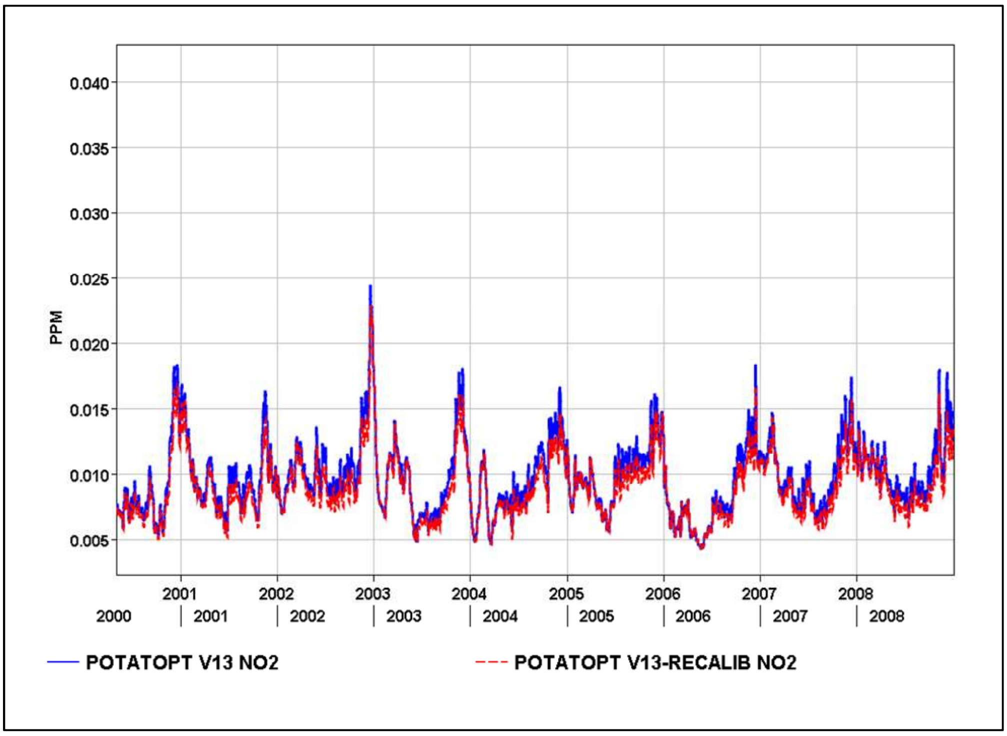
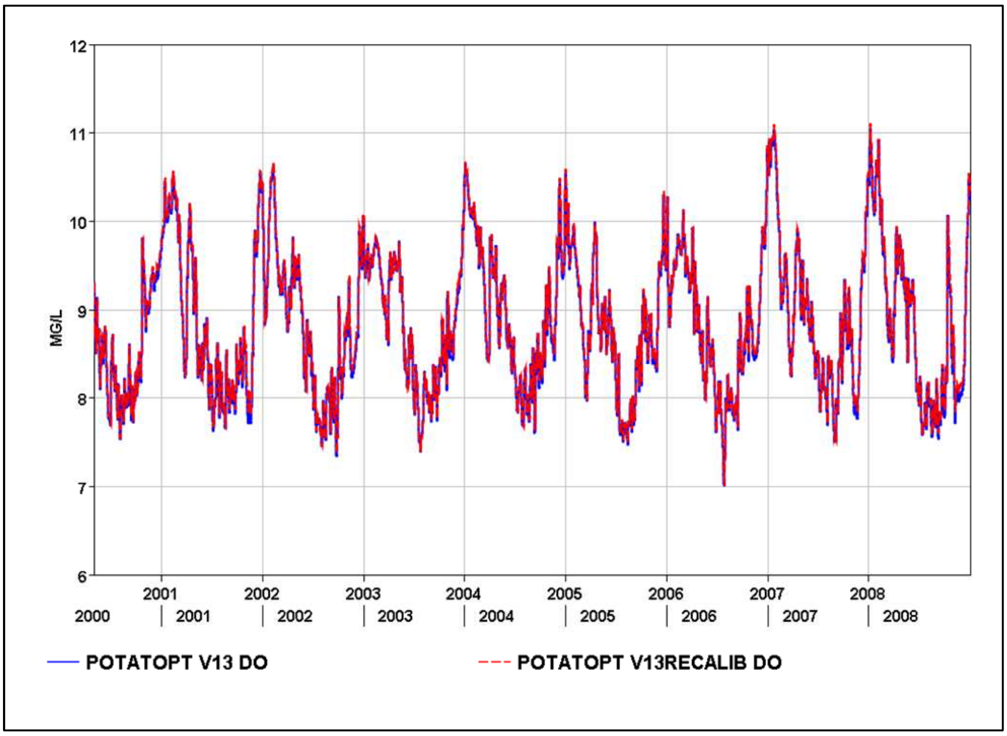


Figure 17-102 Nitrate and nitrite concentrations at Potato Point for Base and Liberty grids.



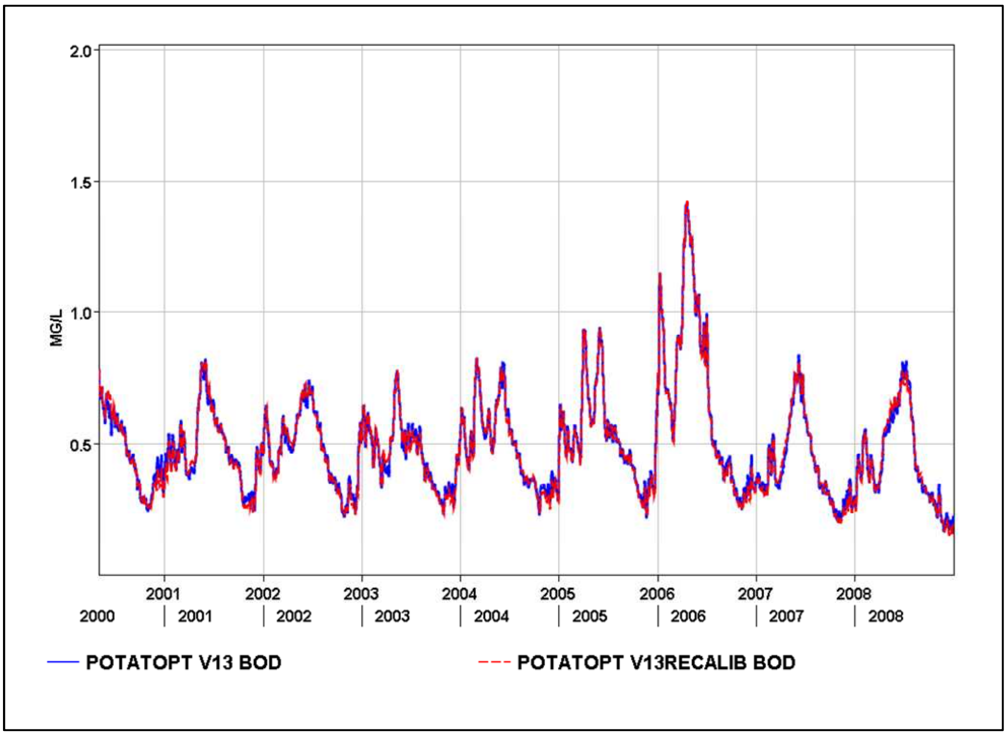
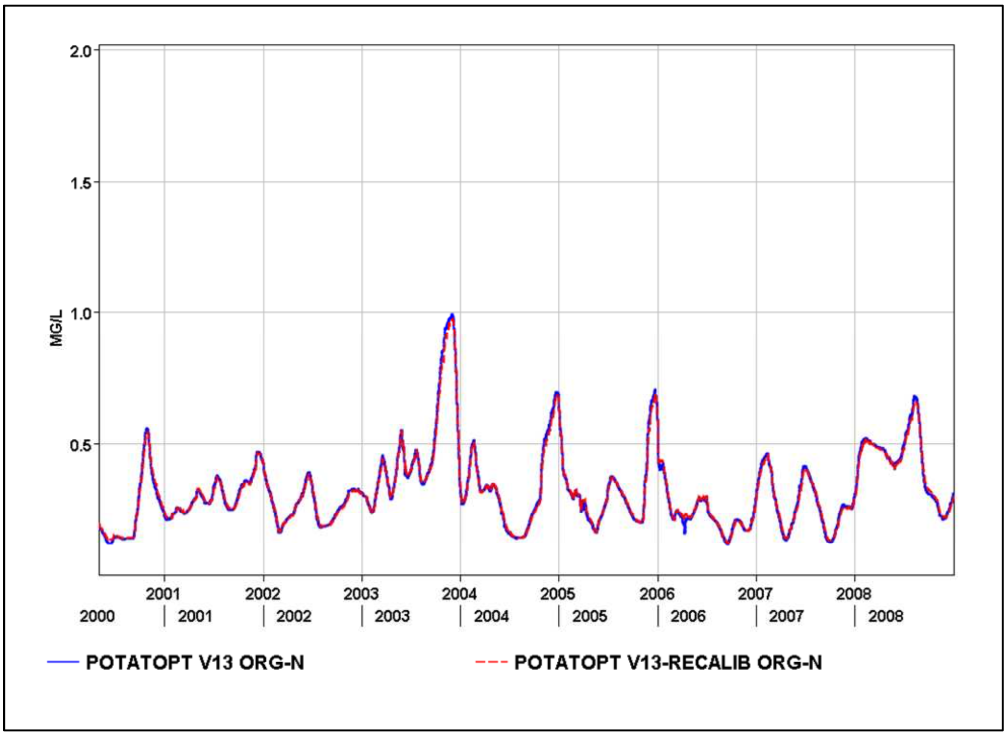


Figure 17-103 DO and CBOD concentrations at Potato Point for Base and Liberty grids.



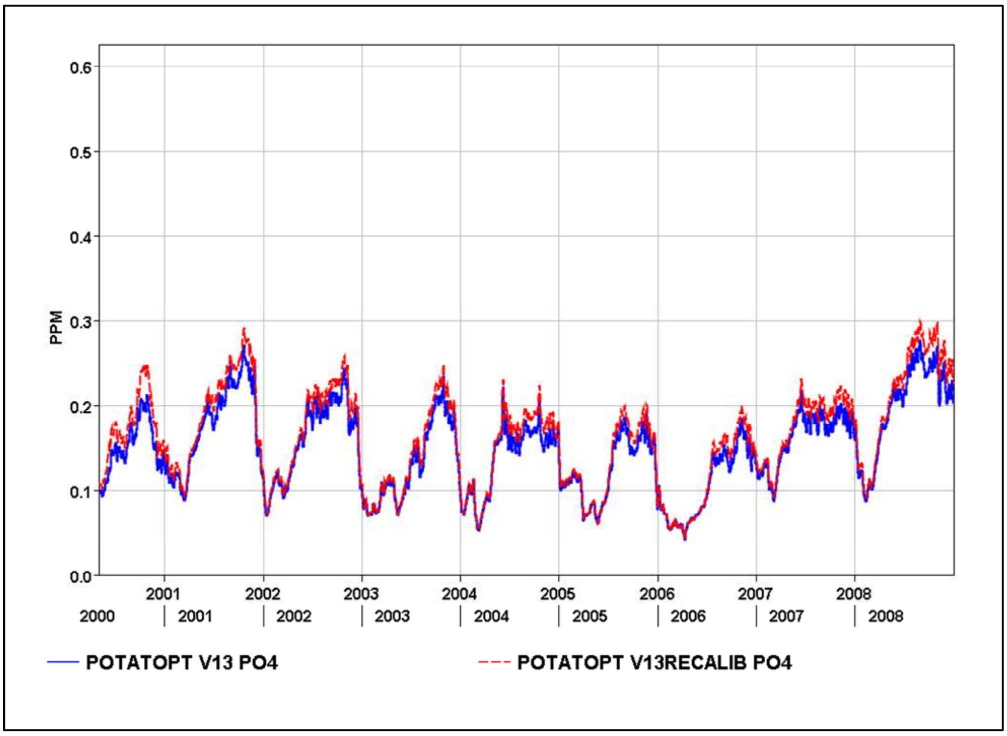


Figure 17-104 Organic-N and PO_4 concentrations at Potato Point for Base and Liberty grids.

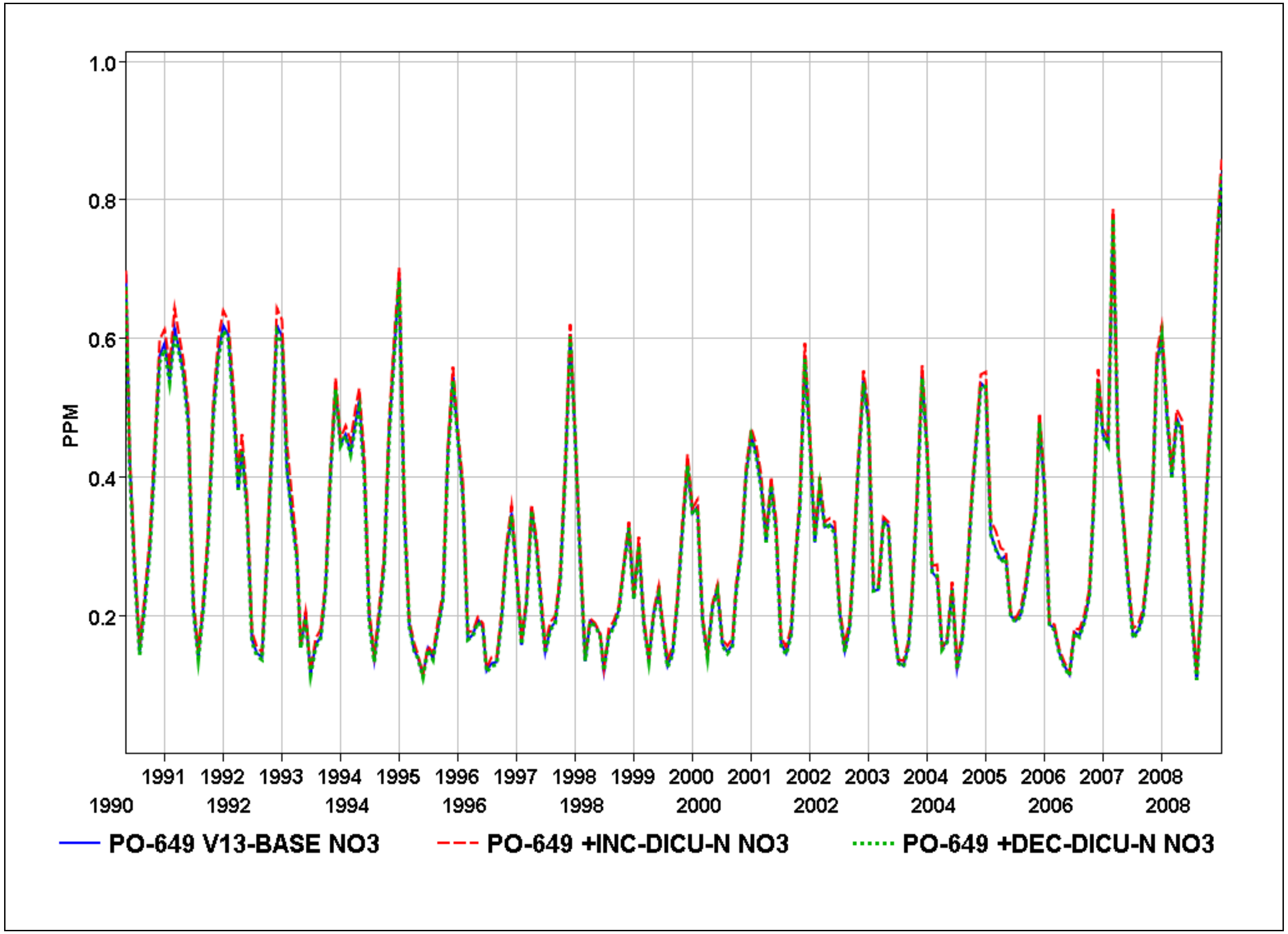


Figure 17-105 Changes in nitrate concentration were very small at Point Sacramento in the DICU changes scenarios.

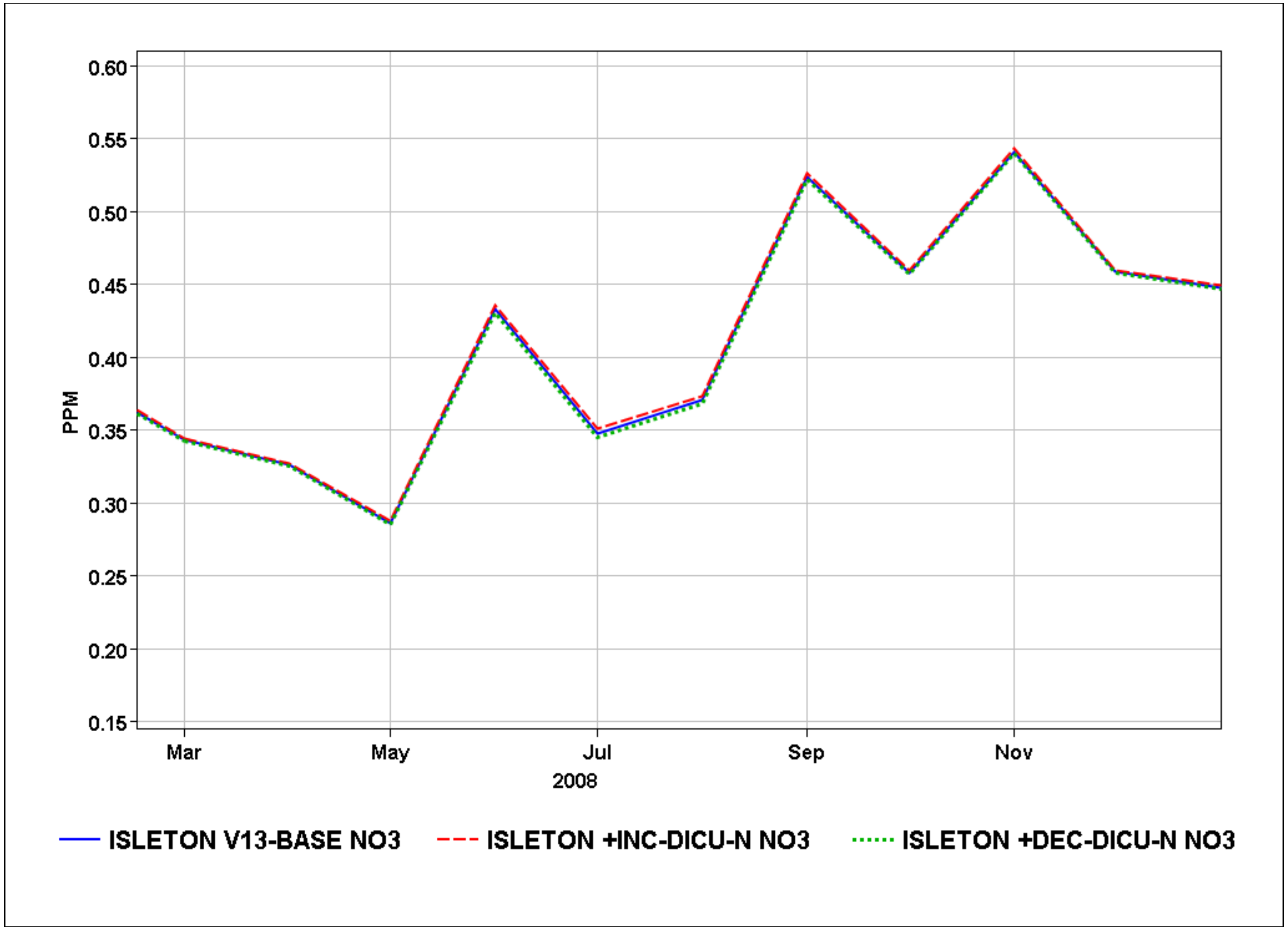


Figure 17-106 Changes in nitrate concentration were hard to distinguish at Isleton in the DICU changes scenarios.

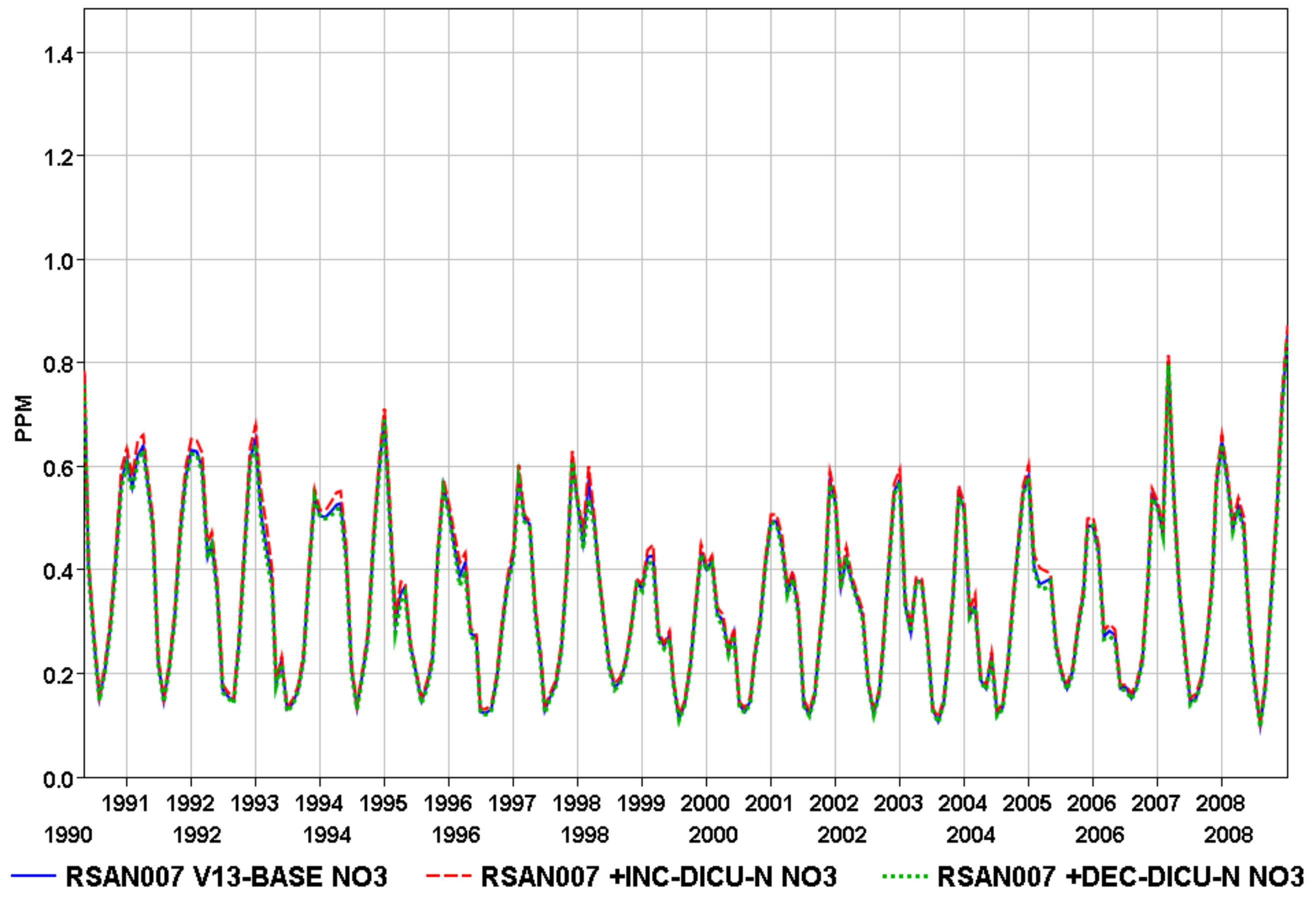


Figure 17-107 Changes in nitrate concentration at Antioch in the DICU changes scenarios.

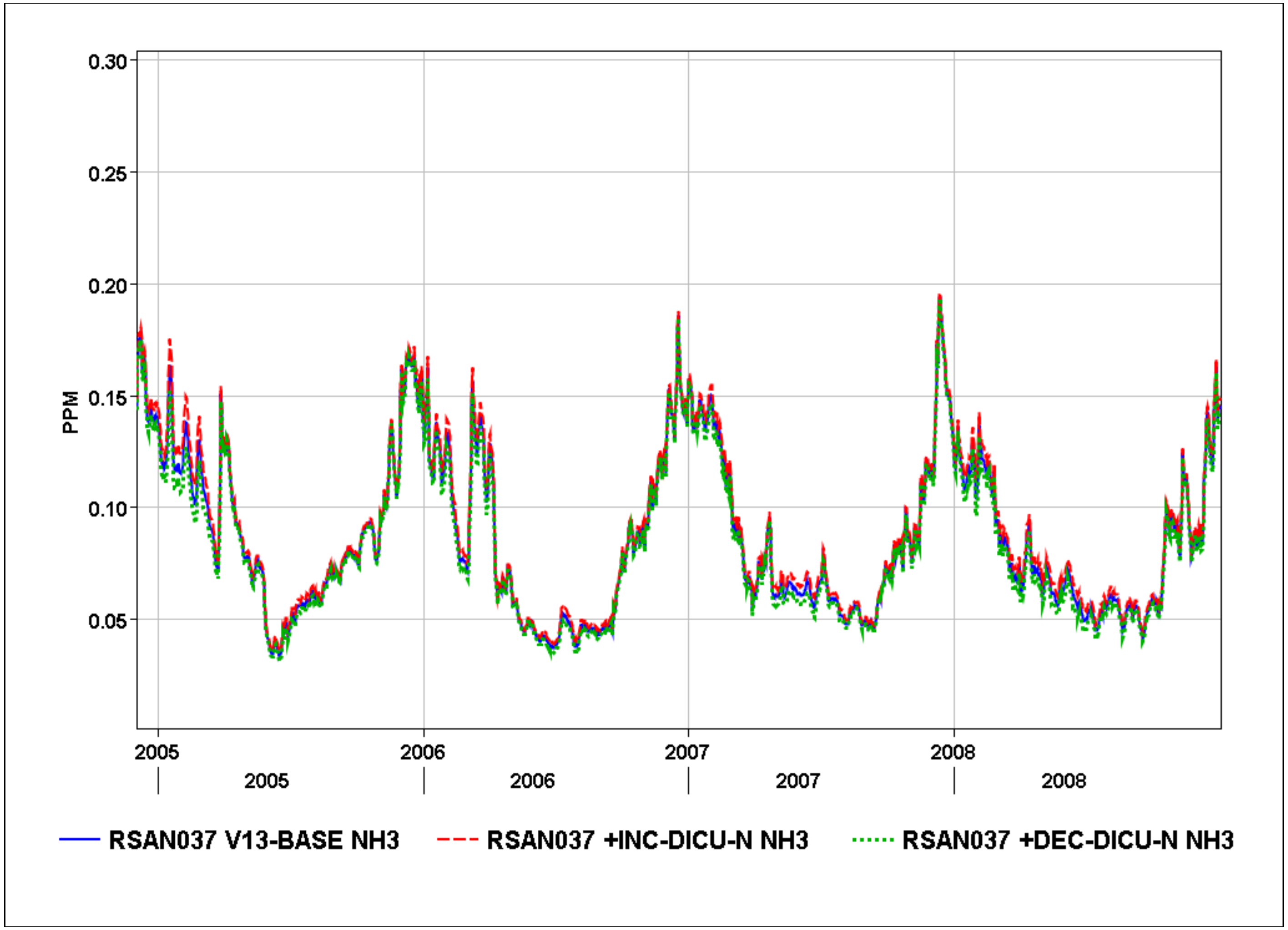


Figure 17-108 Changes in ammonia concentration at RSAN037 on the San Joaquin River.

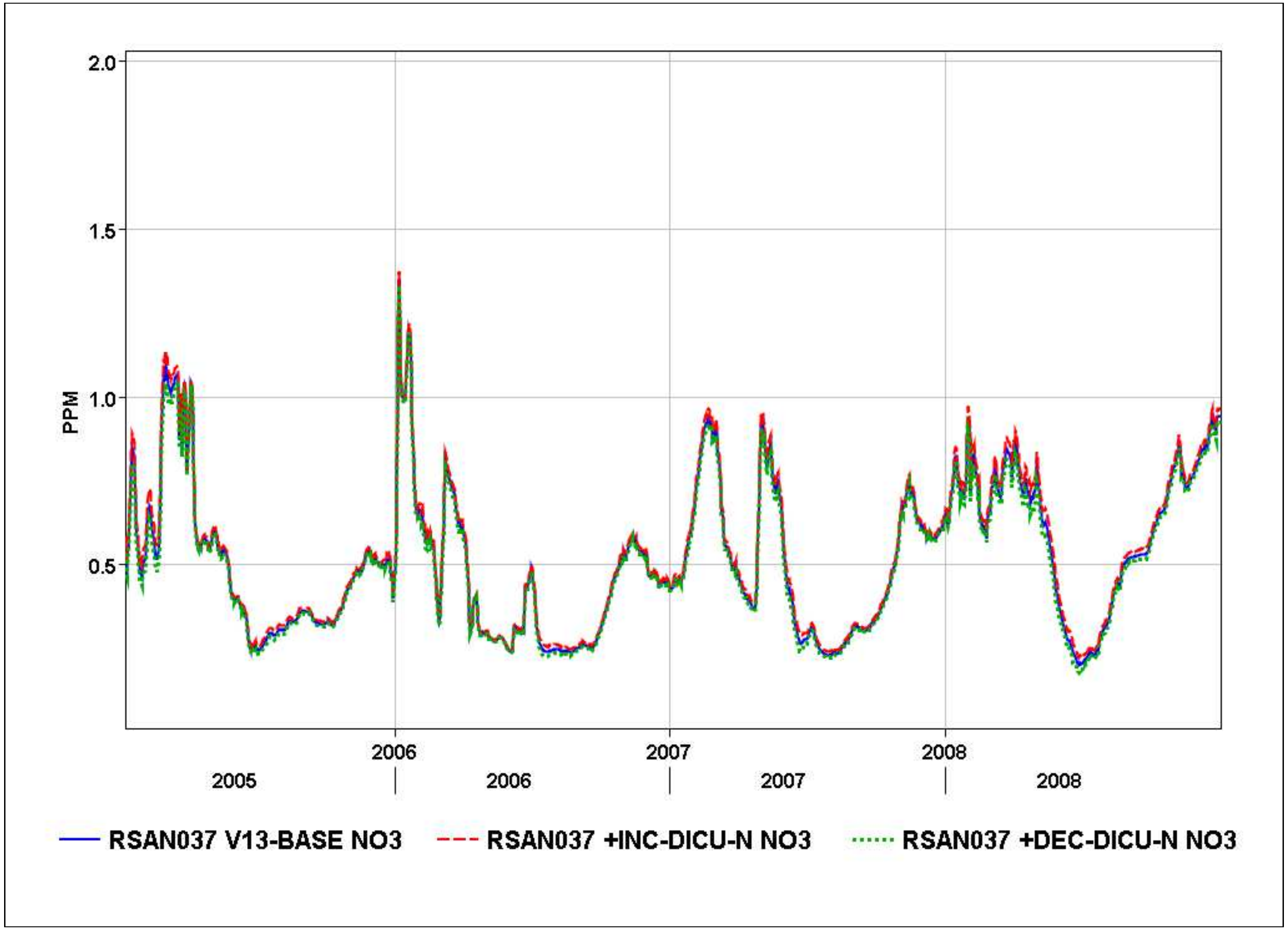


Figure 17-109 Changes in nitrate concentration at RSAN037 on the San Joaquin River.

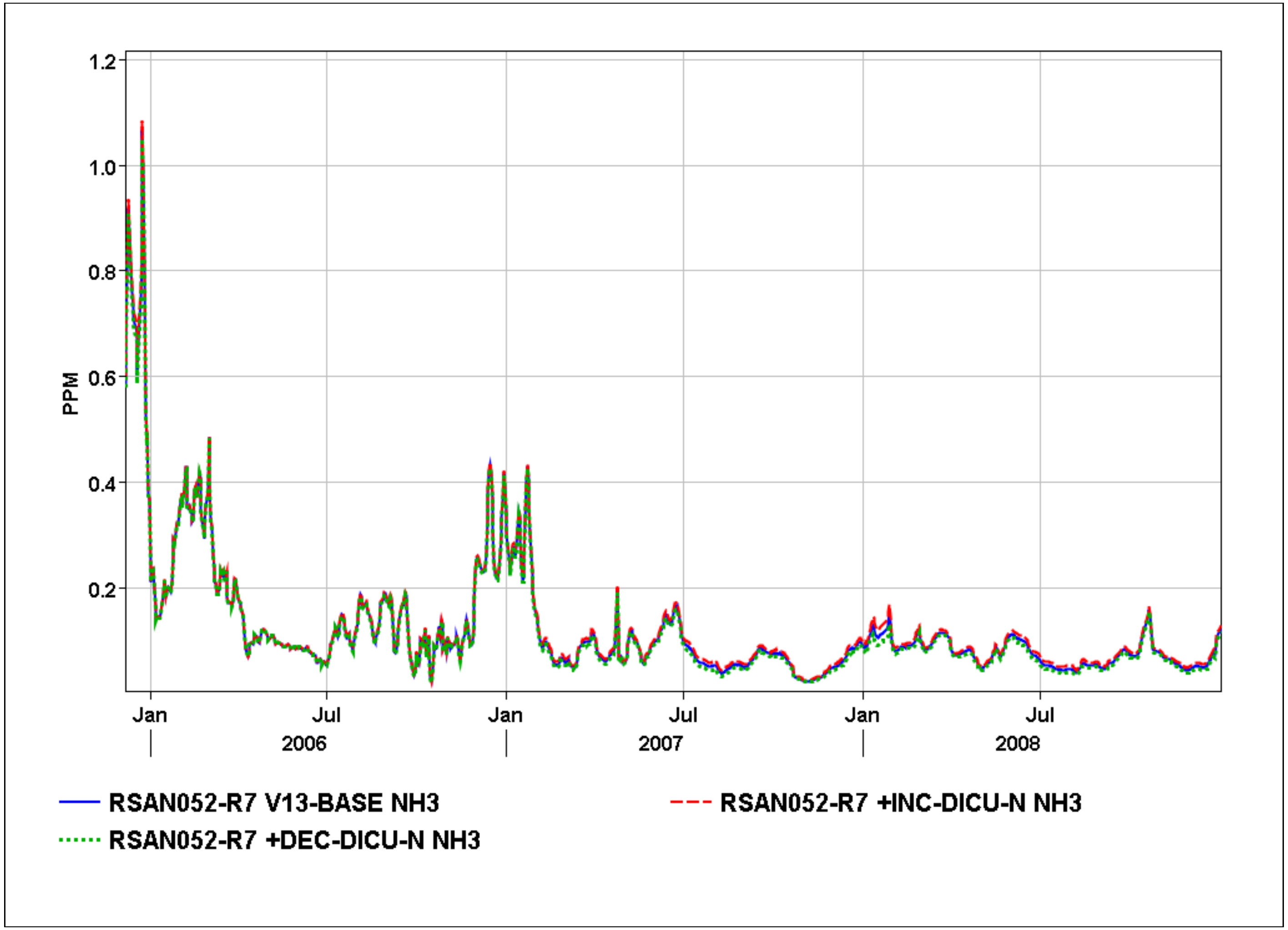


Figure 17-110 Changes in ammonia concentration at RSAN052 on the San Joaquin River.

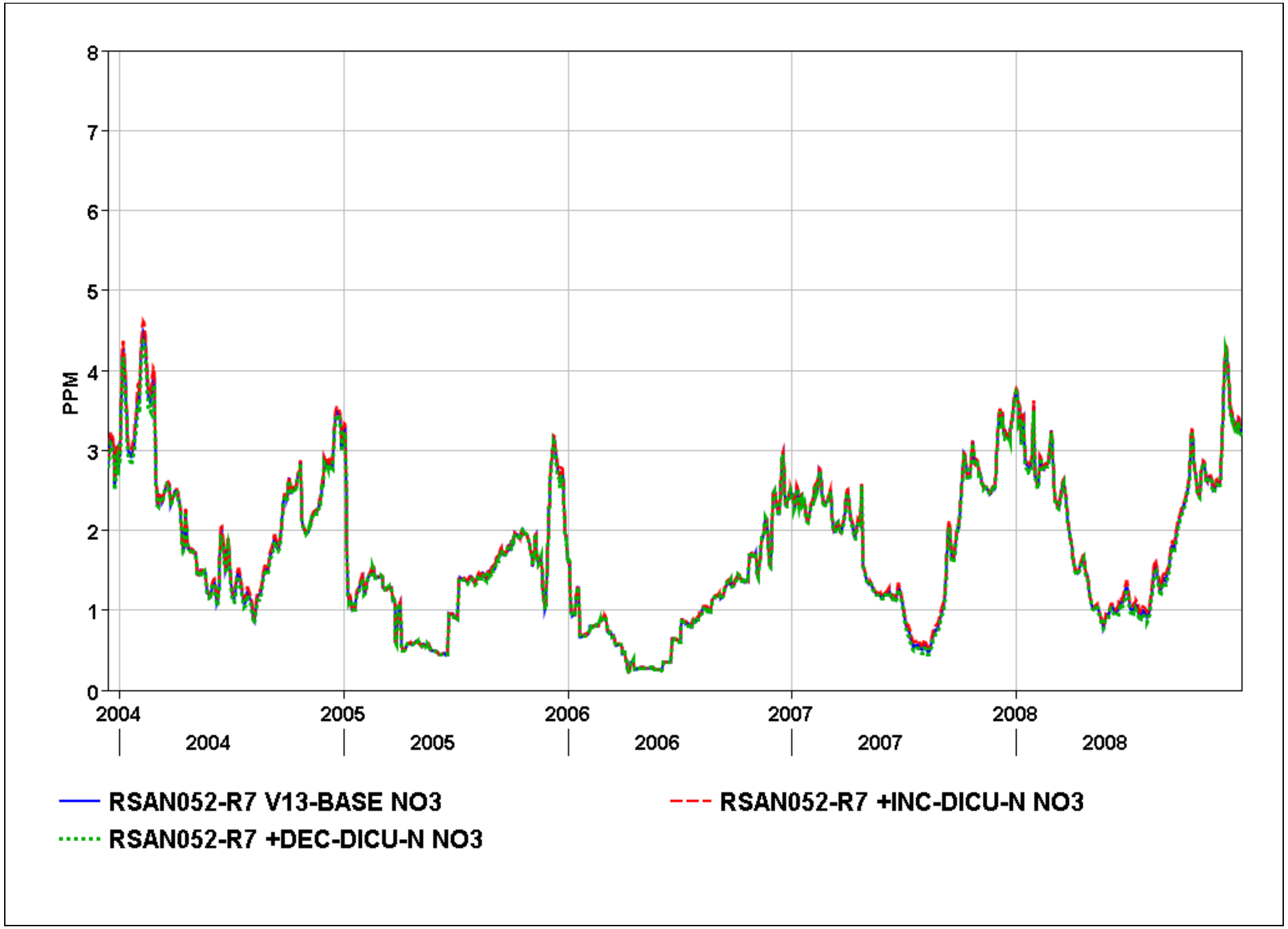


Figure 17-111 Changes in nitrate concentration at RSAN052 on the San Joaquin River.

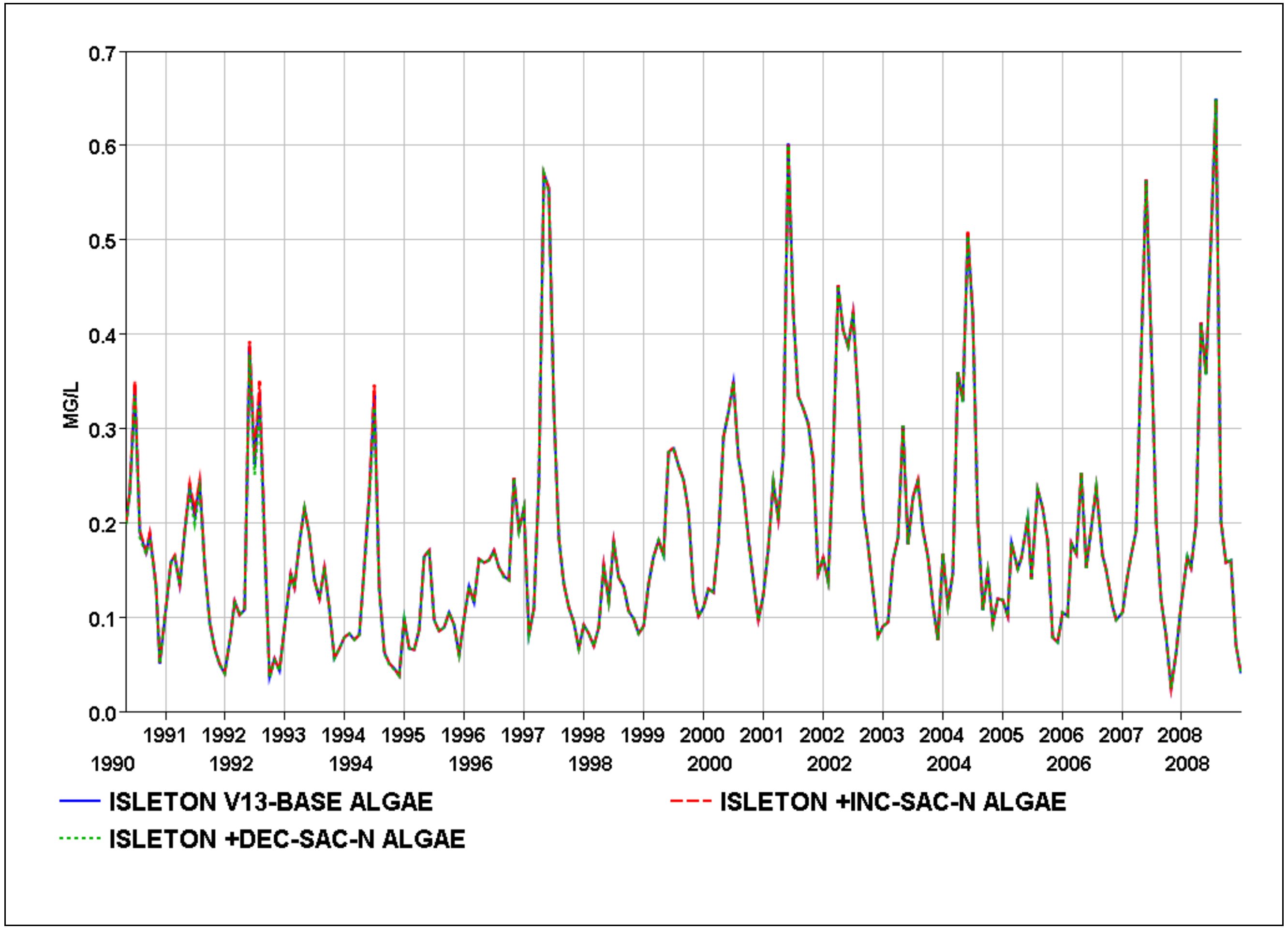


Figure 17-112 Changes in algal biomass were very small at Isleton for the scenarios changing Sacramento R. N-constituents.

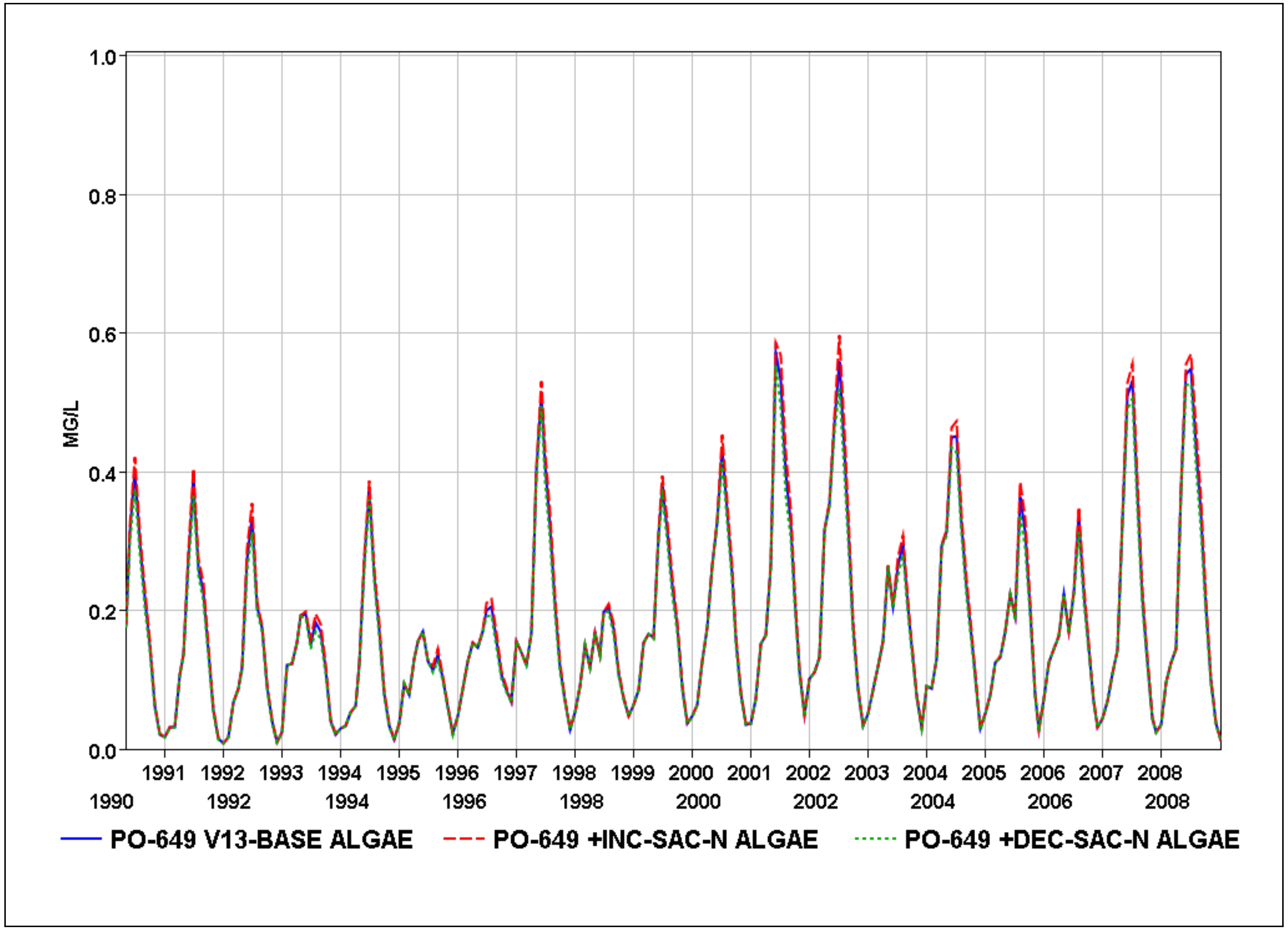


Figure 17-113 Changes in algal biomass were very small at Point Sacramento for the scenarios changing Sacramento R. N-constituents.

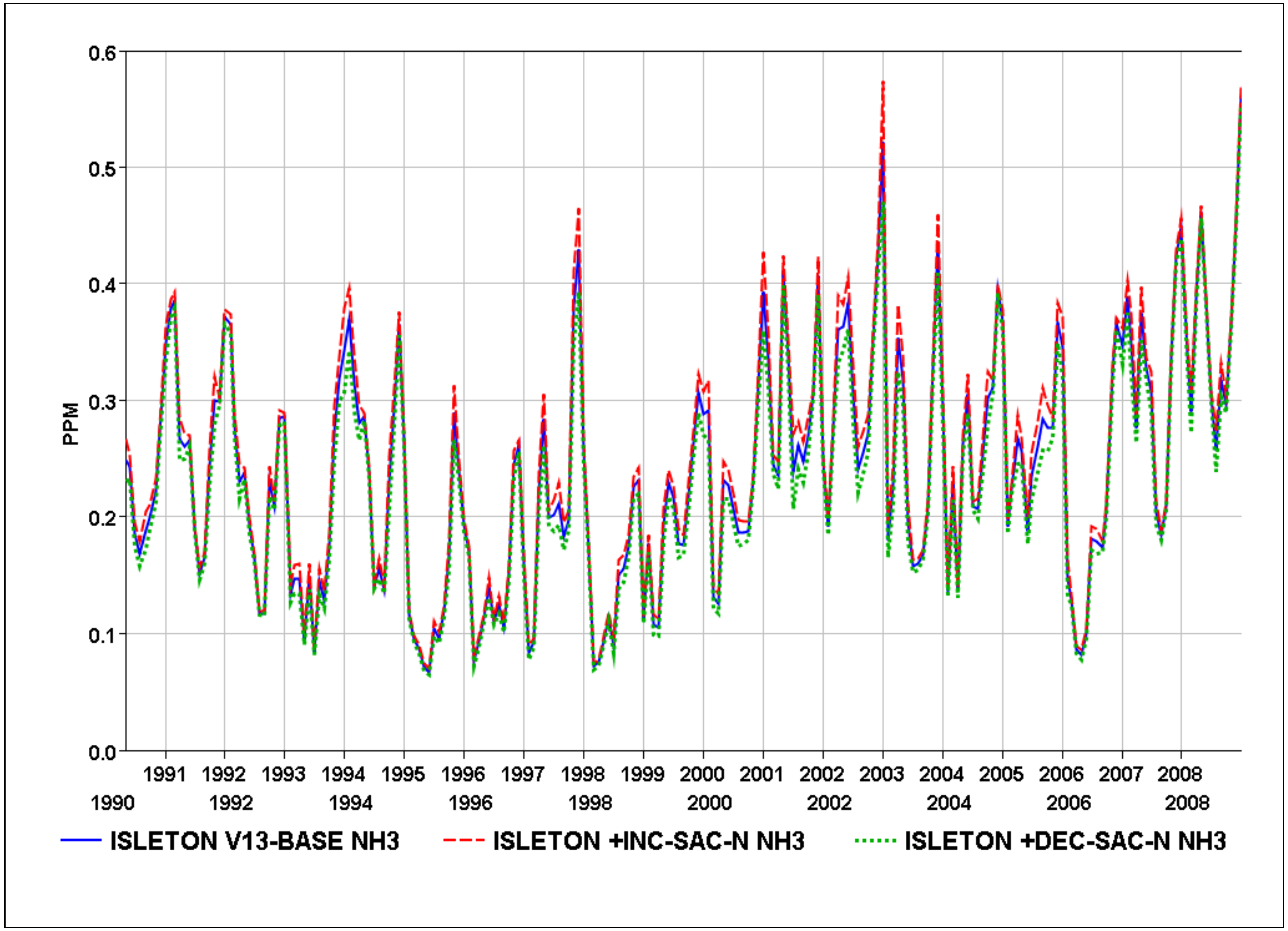


Figure 17-114 Changes in ammonia at Isleton for the scenarios changing Sacramento R. N-constituents.

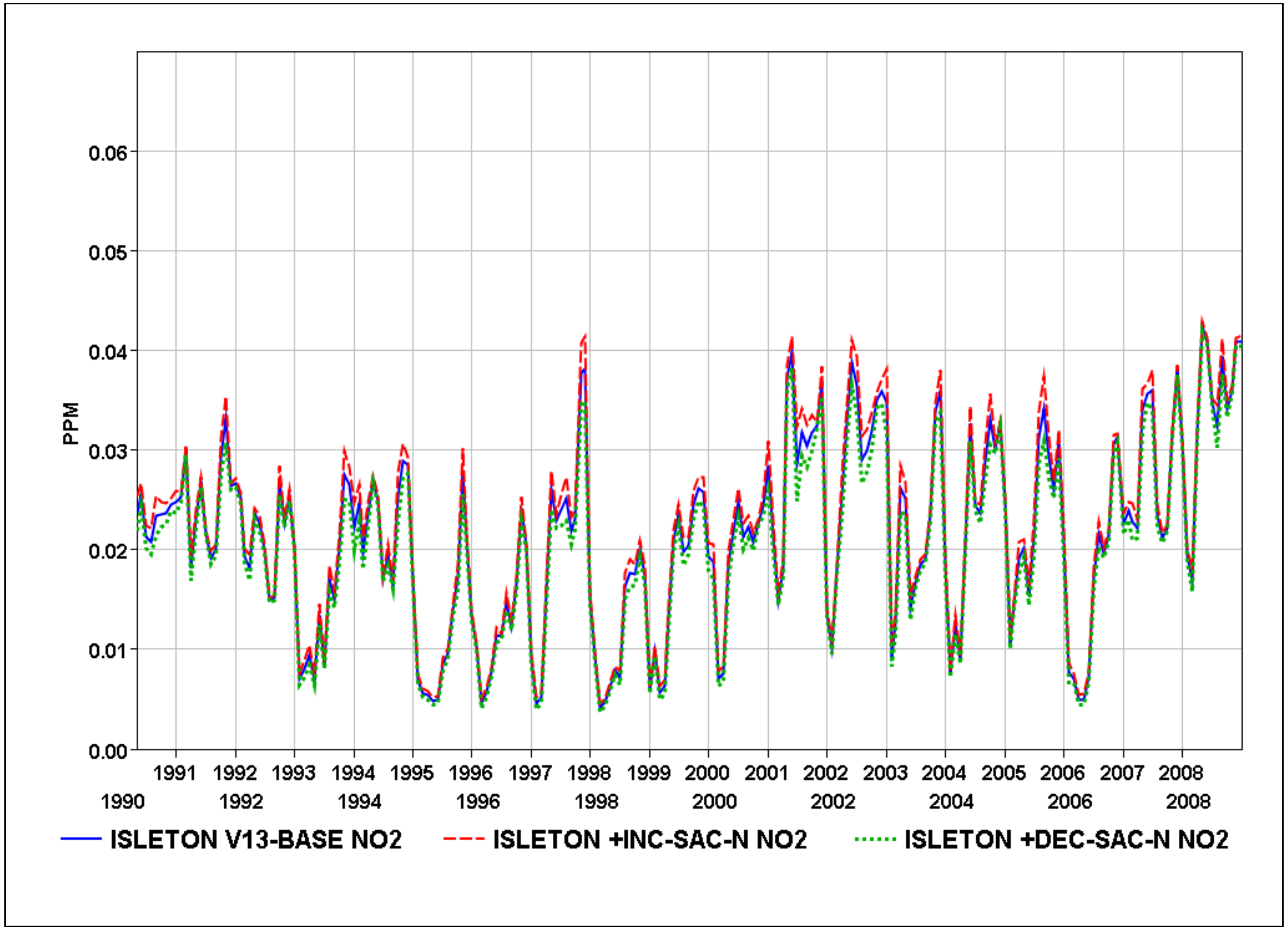


Figure 17-115 Changes in nitrite at Isleton for the scenarios changing Sacramento R. N-constituents.

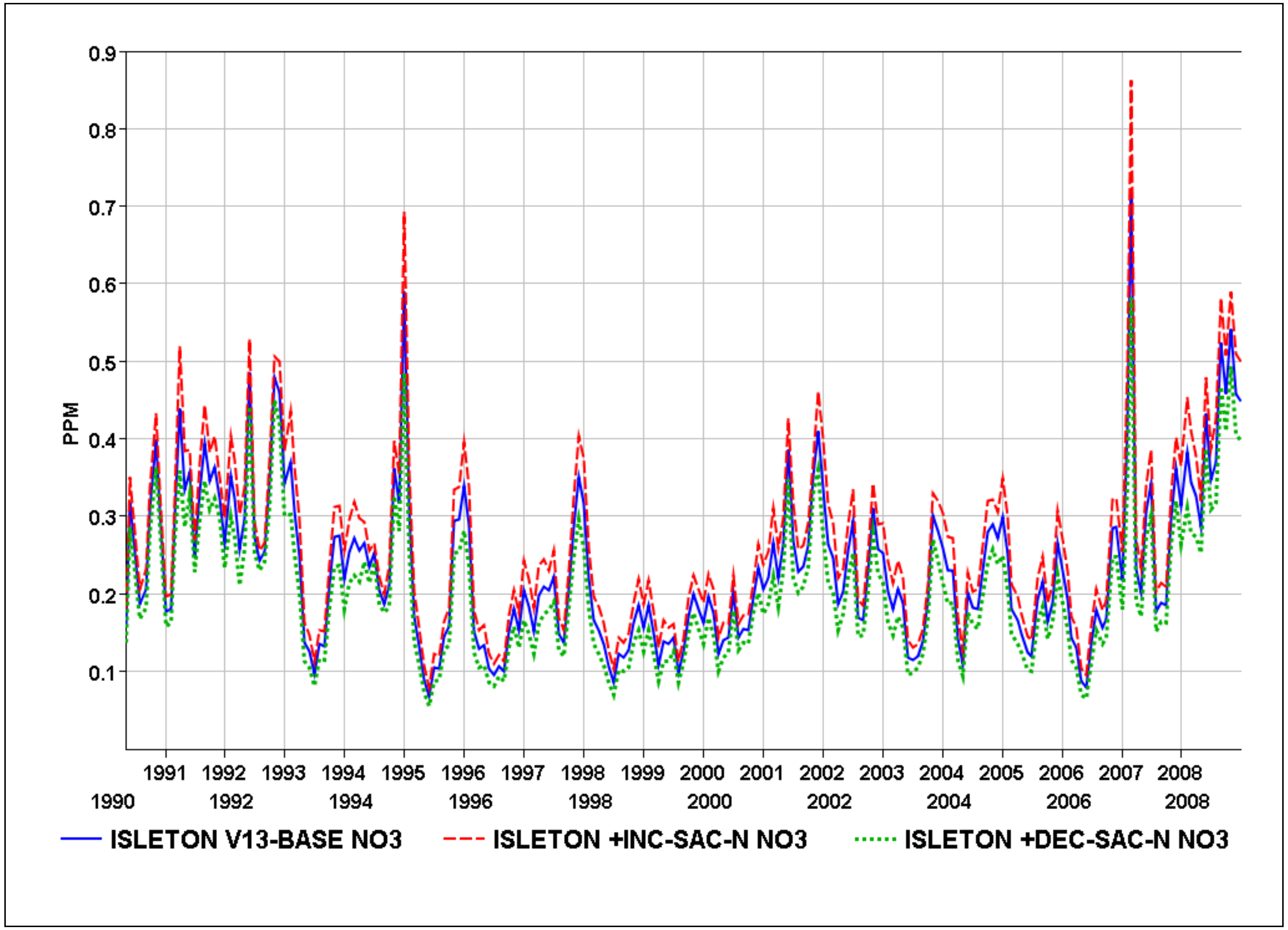


Figure 17-116 Changes in nitrate at Isleton for the scenarios changing Sacramento R. N-constituents.

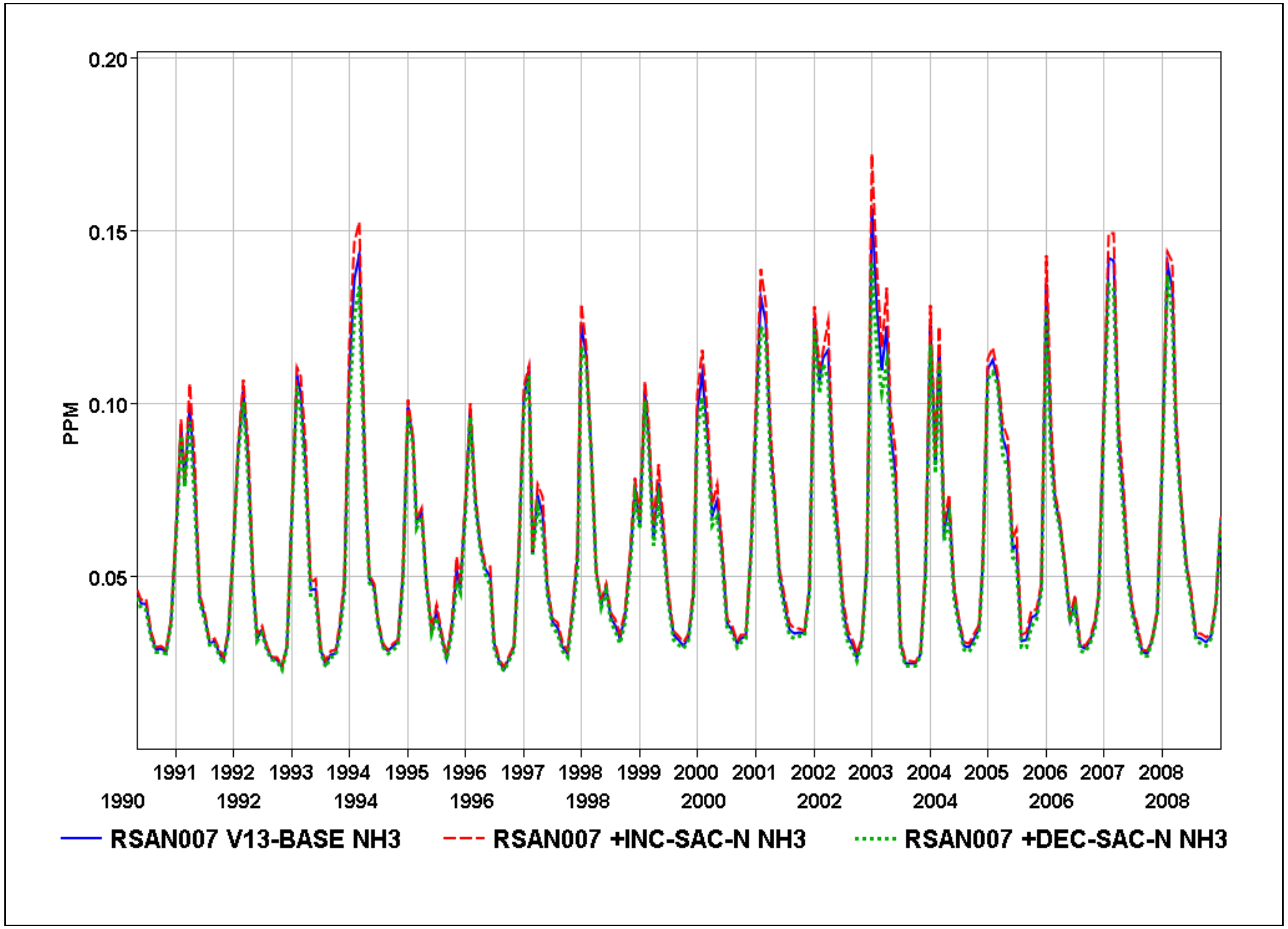


Figure 17-117 Changes in ammonia concentration at Antioch for the scenarios changing Sacramento R. N-constituents.

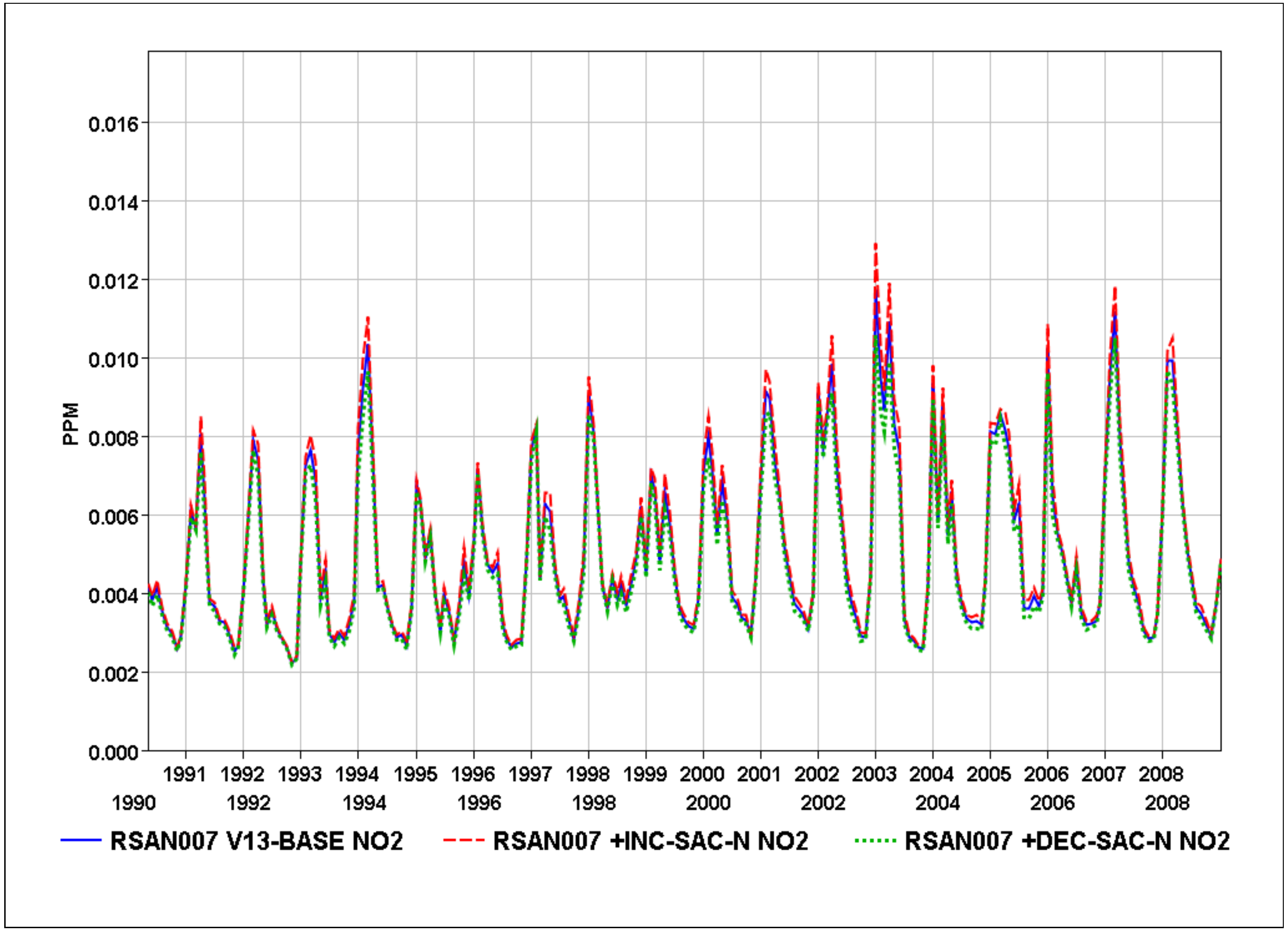


Figure 17-118 Changes in nitrite concentration at Antioch for the scenarios changing Sacramento R. N-constituents.

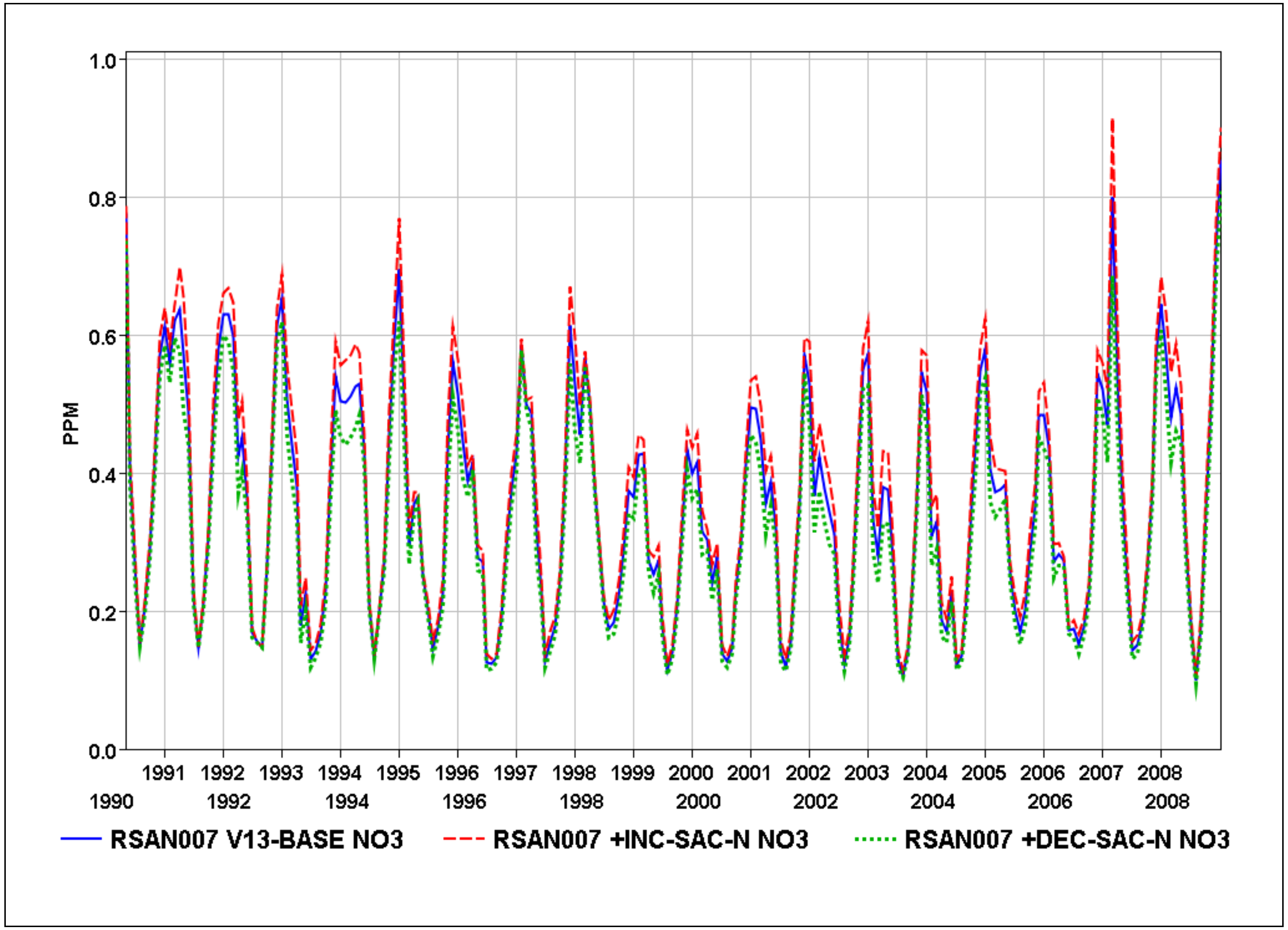


Figure 17-119 Changes in nitrate concentration at Antioch for the scenarios changing Sacramento R. N-constituents

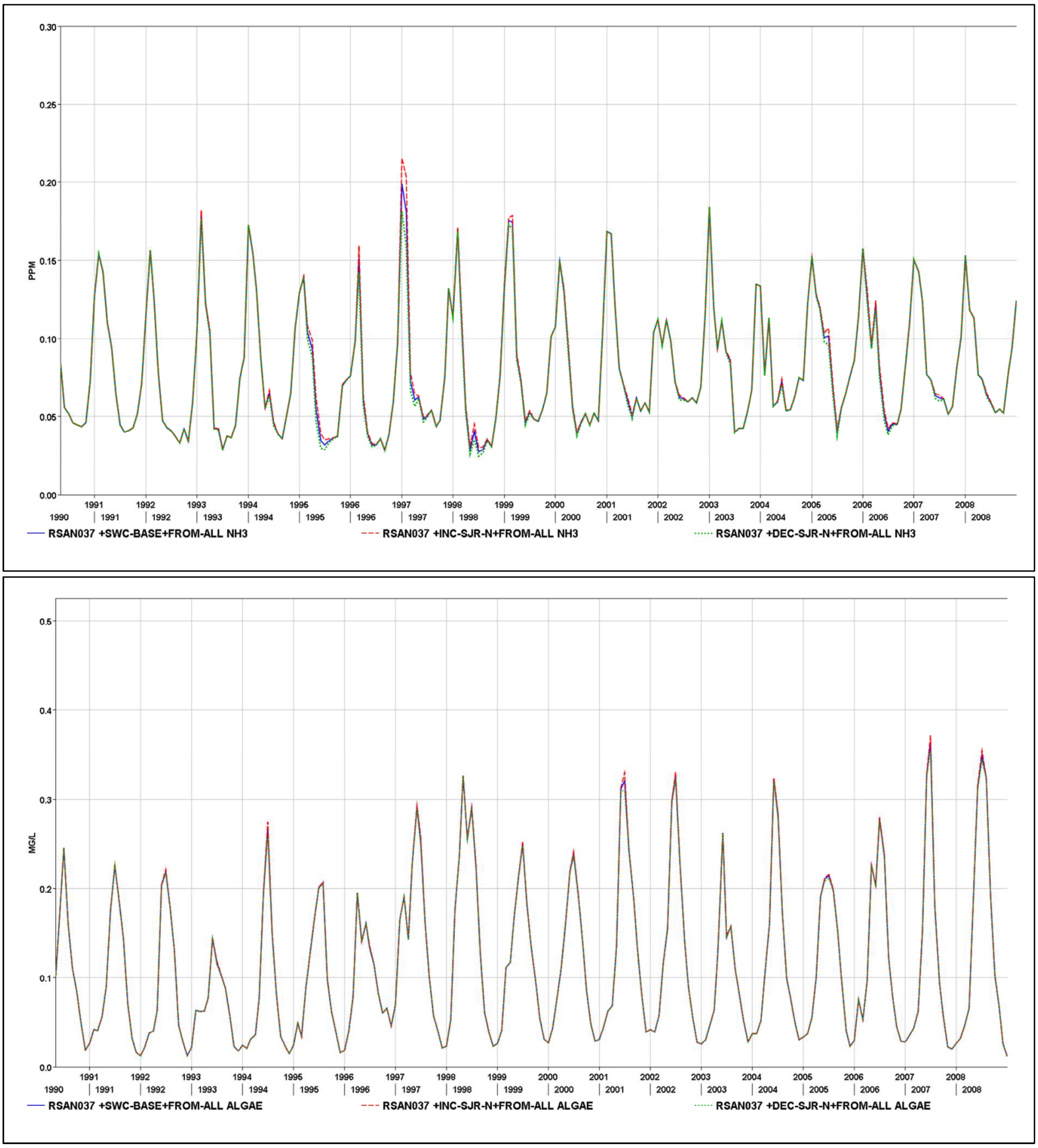
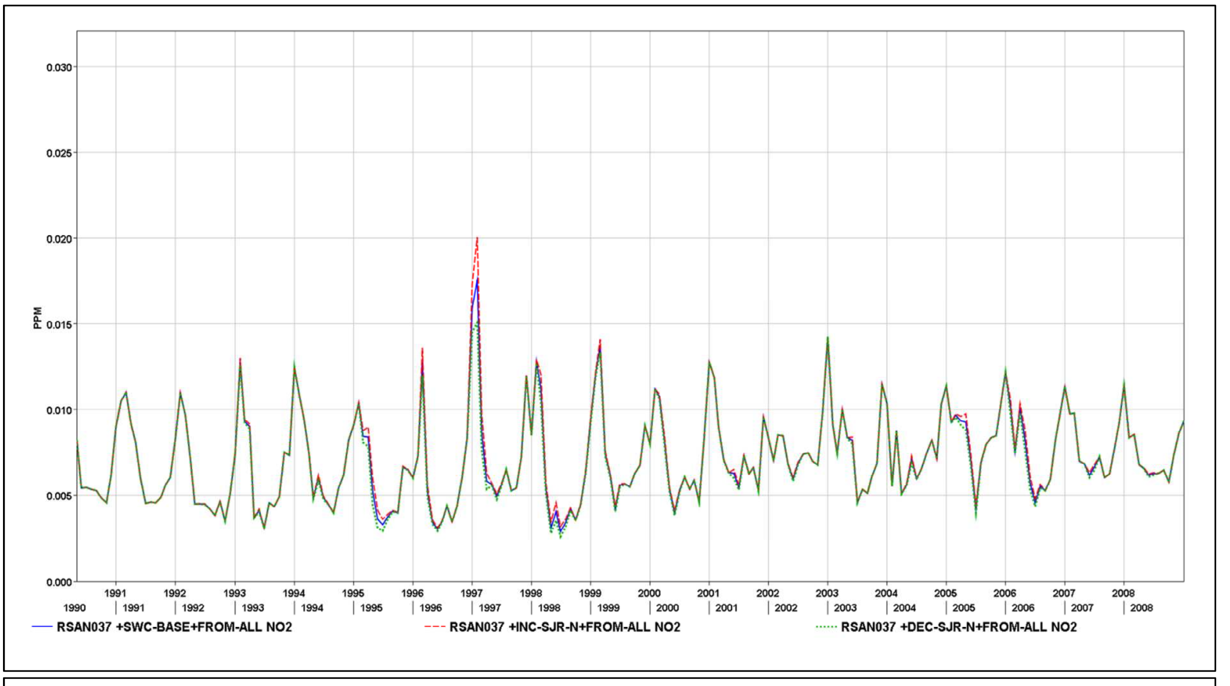


Figure 17-120 Ammonia and chl-a/algae concentrations at RSAN037 downstream the San Joaquin boundary.



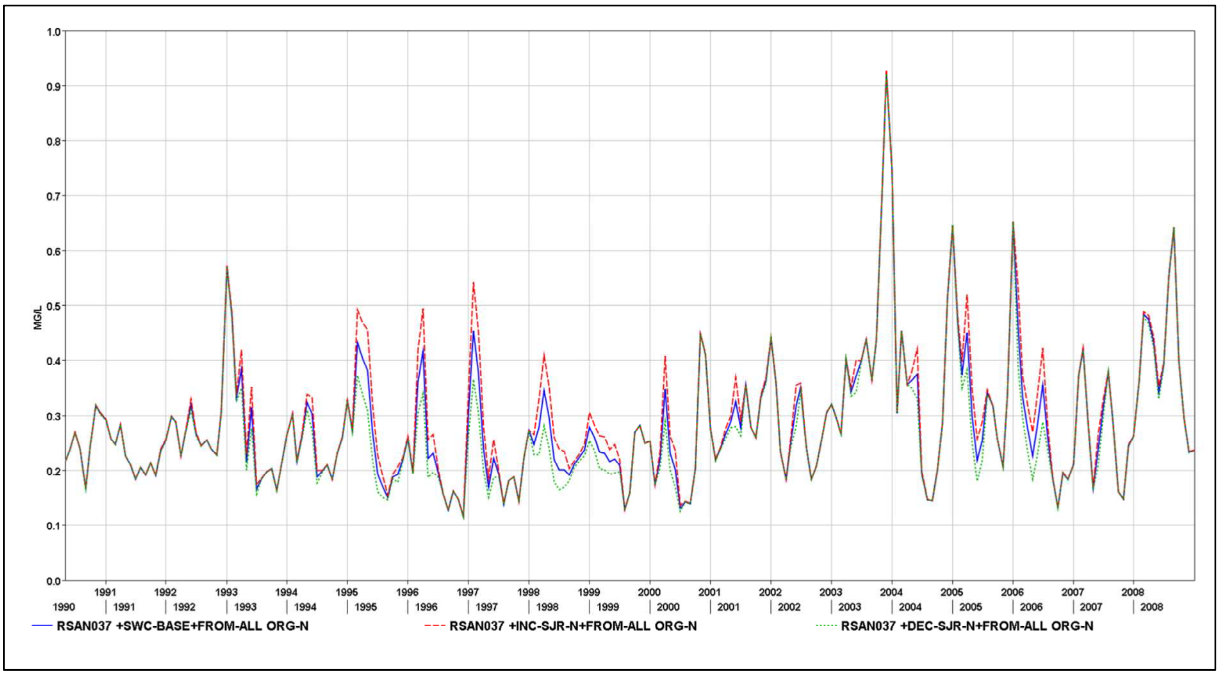
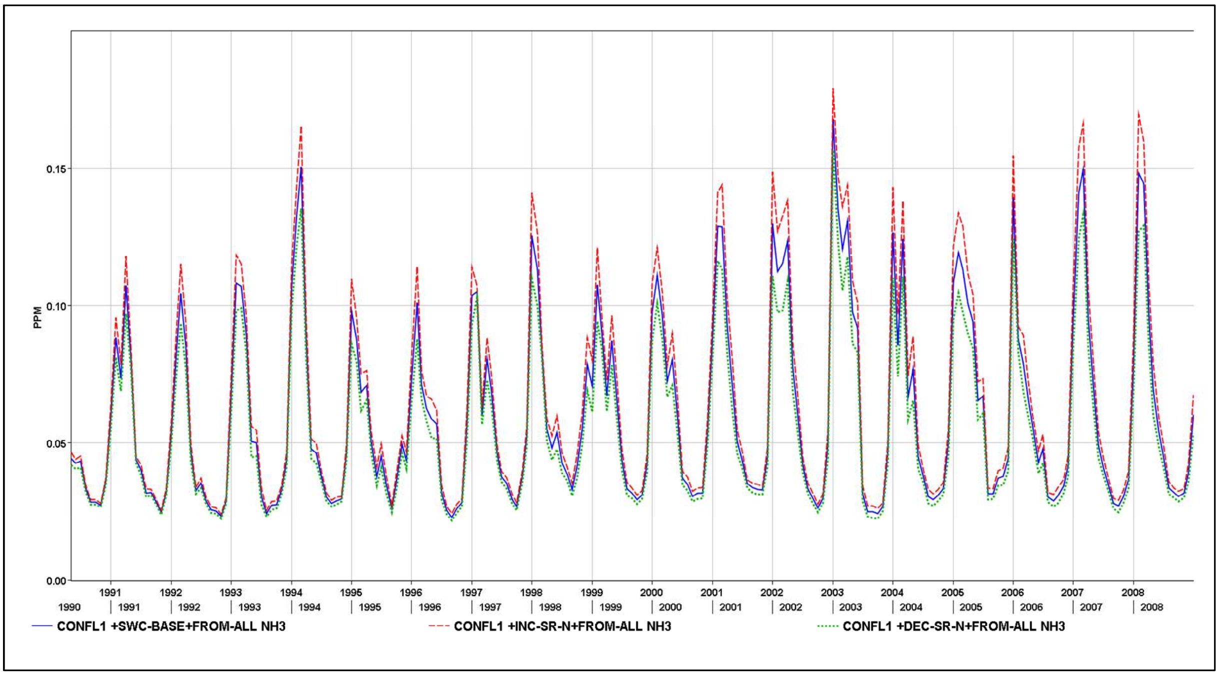


Figure 17-121 Nitrite and organic-N concentrations at RSAN037 downstream of the San Joaquin boundary.



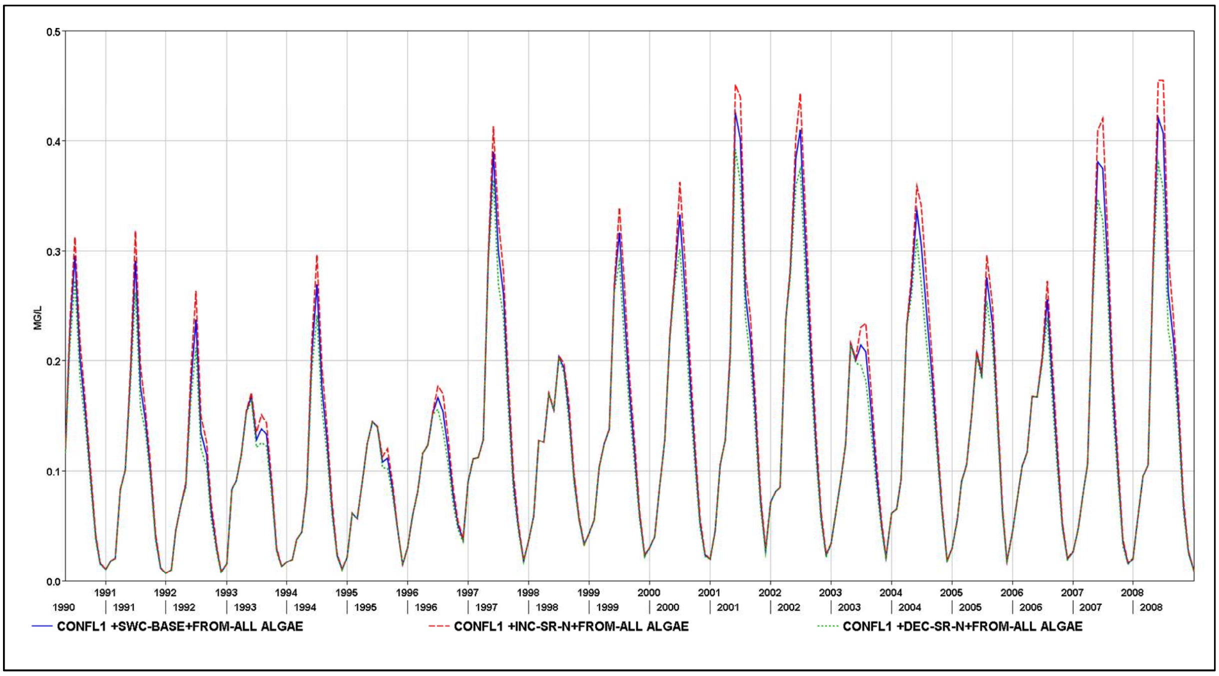
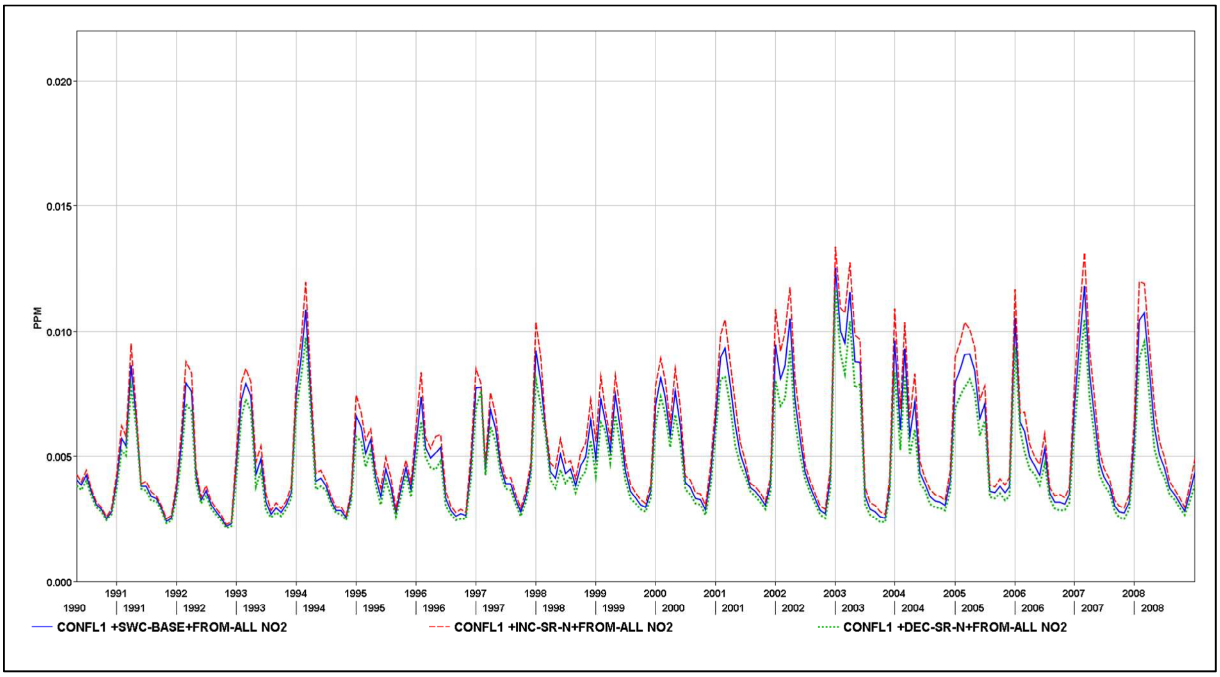


Figure 17-122 Changes in ammonia and chl-a/algae at the Confluence-1 location in the scenario changing Sac Regional N-constituents.



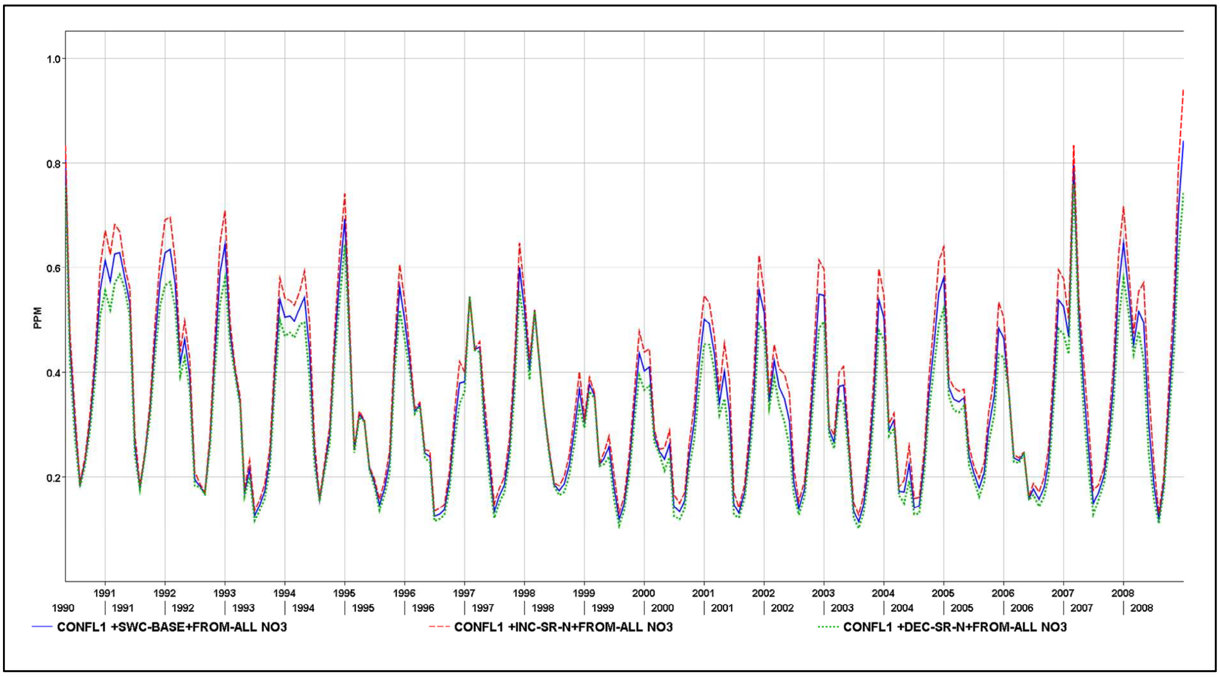
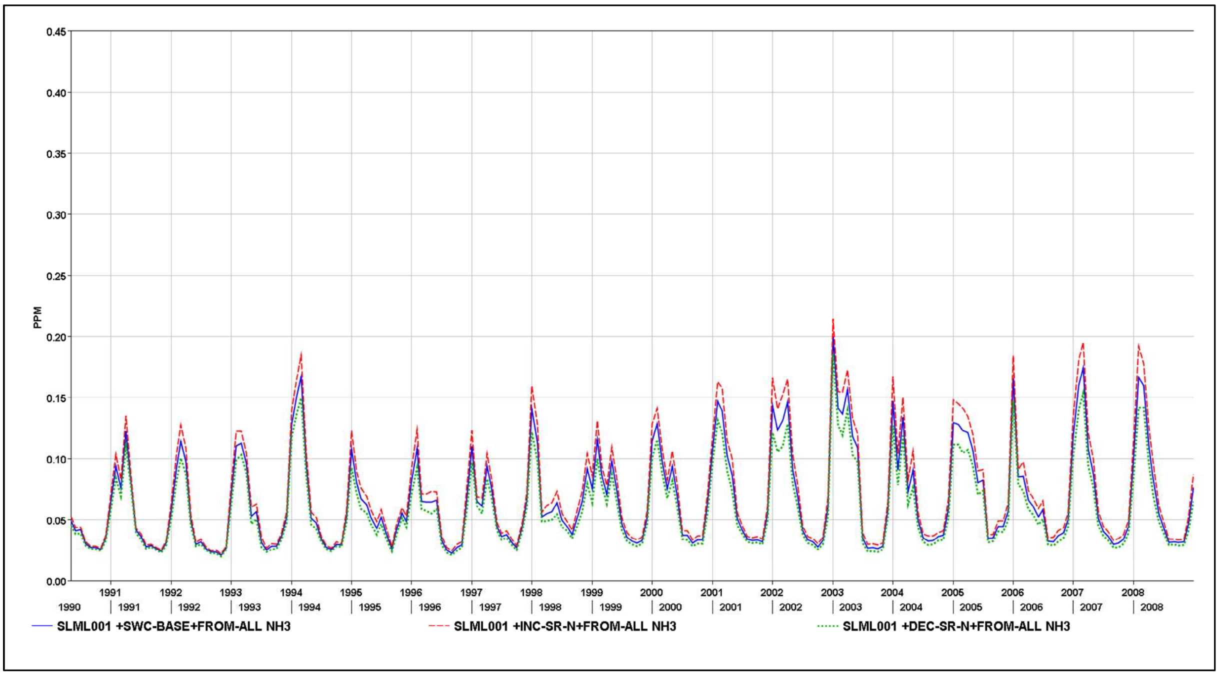


Figure 17-123 Changes in nitrite and nitrate at the Confluence-1 location in the scenario changing Sac Regional N-constituents.



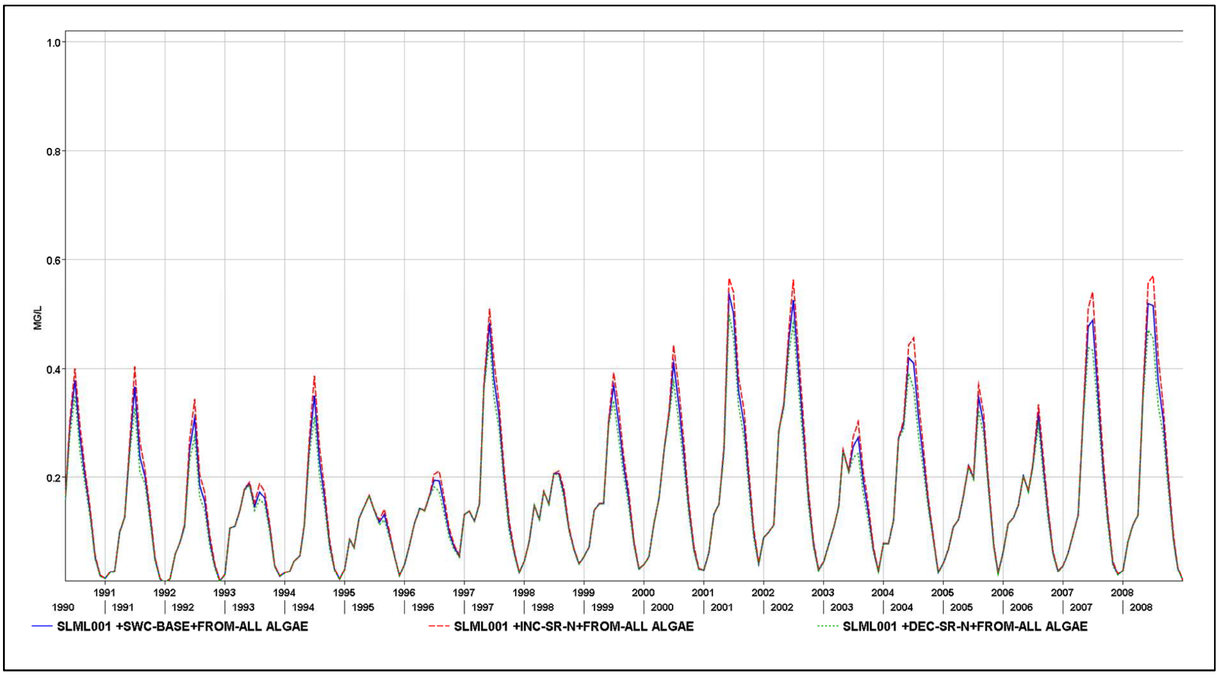
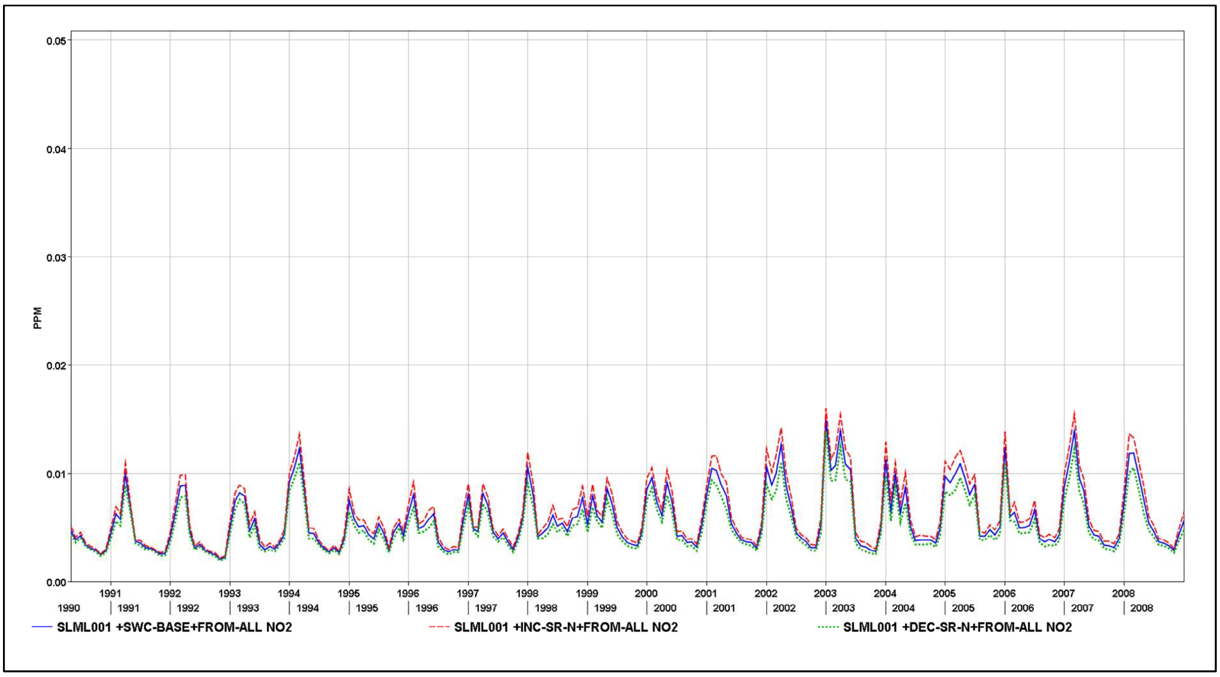


Figure 17-124 Changes in ammonia and chl-a/algae at Suisun at Nichols in the scenario changing Sac Regional N-constituents.



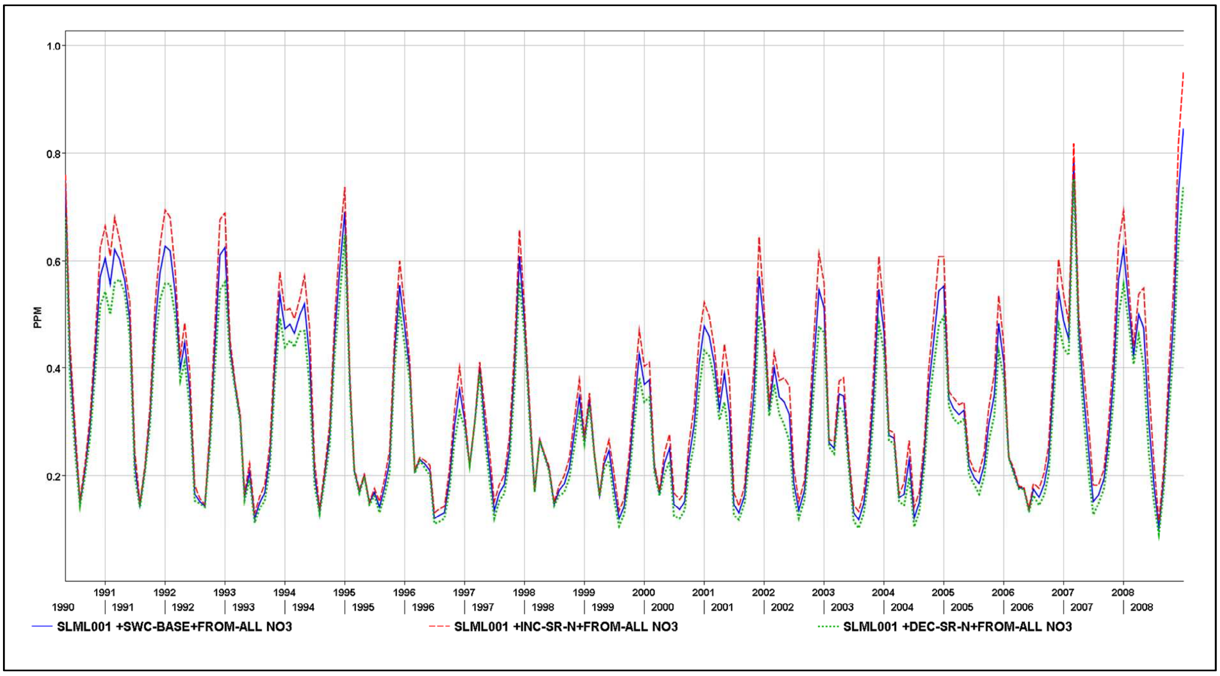
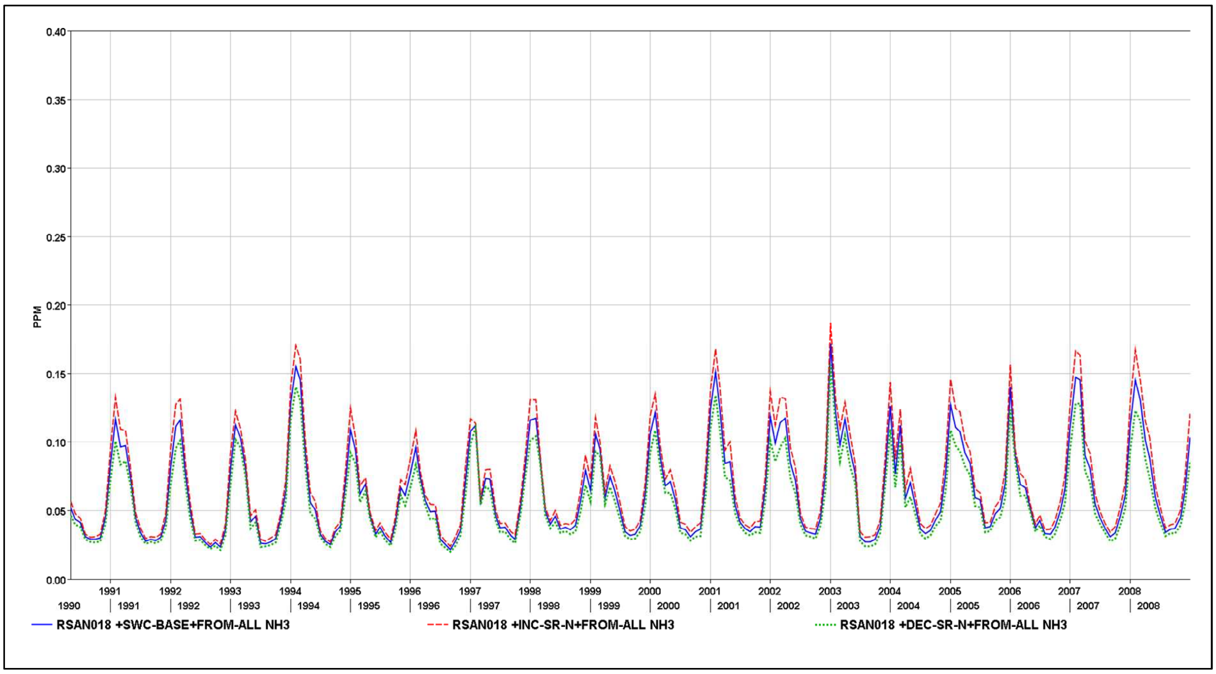


Figure 17-125 Changes in nitrite and nitrate at Suisun Nichols in the scenario changing Sac Regional N-constituents.



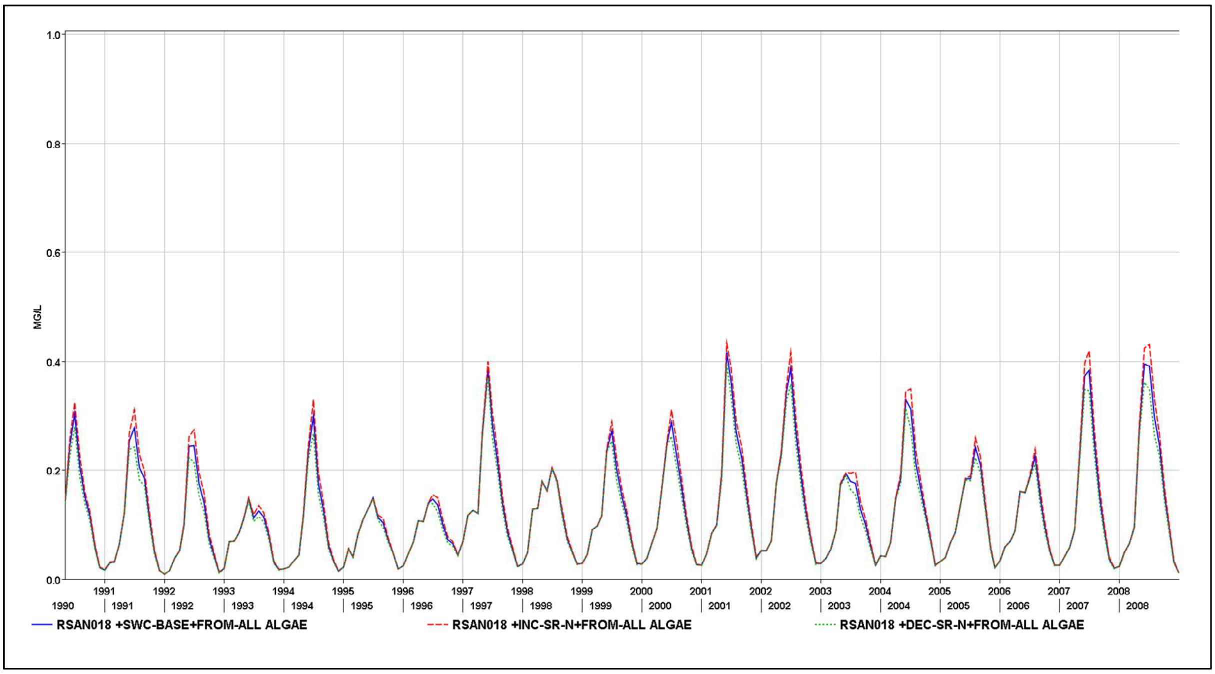
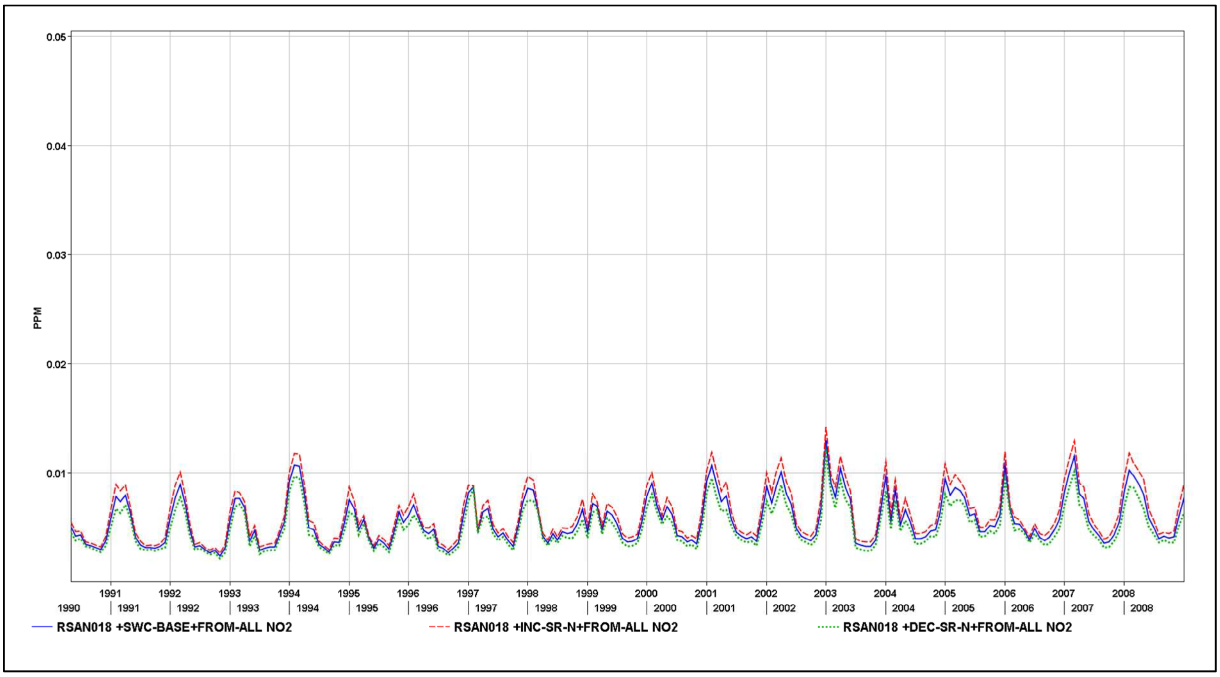


Figure 17-126 Changes in ammonia and chl-a/alga at Jersey point (RSAN018) in the scenario changing Sac Regional N-constituents.



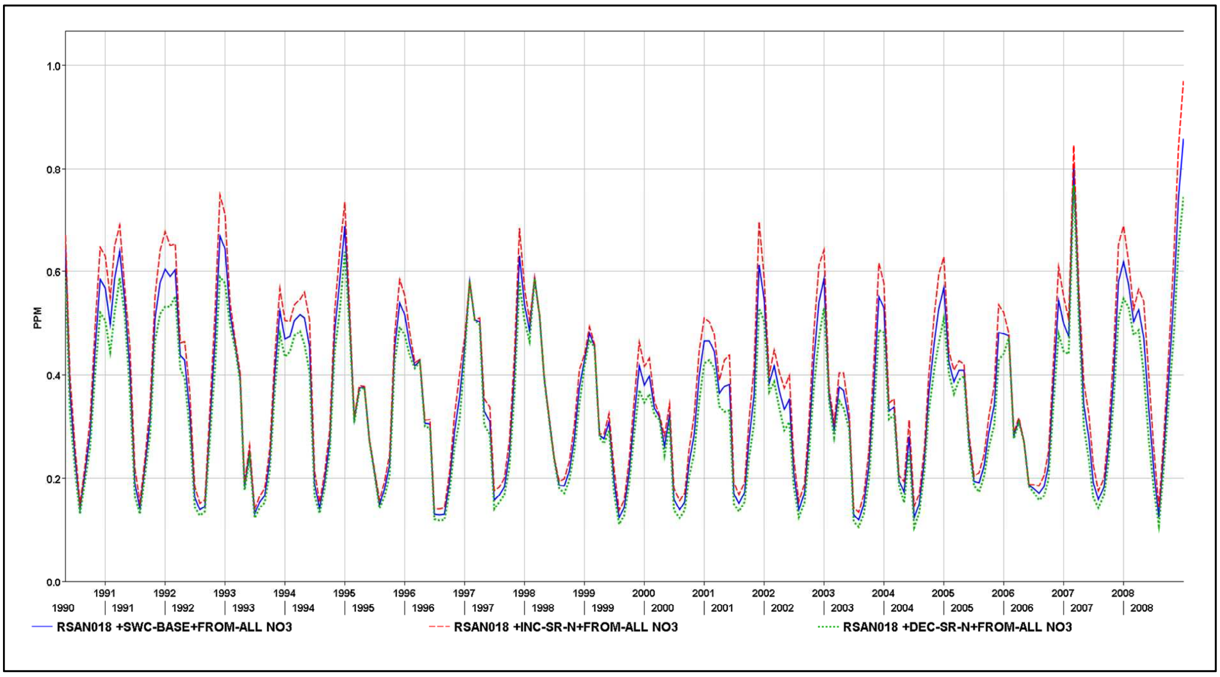


Figure 17-127 Changes in nitrite and nitrate at Jersey point (RSAN018) in the scenario changing Sac Regional N-constituents.

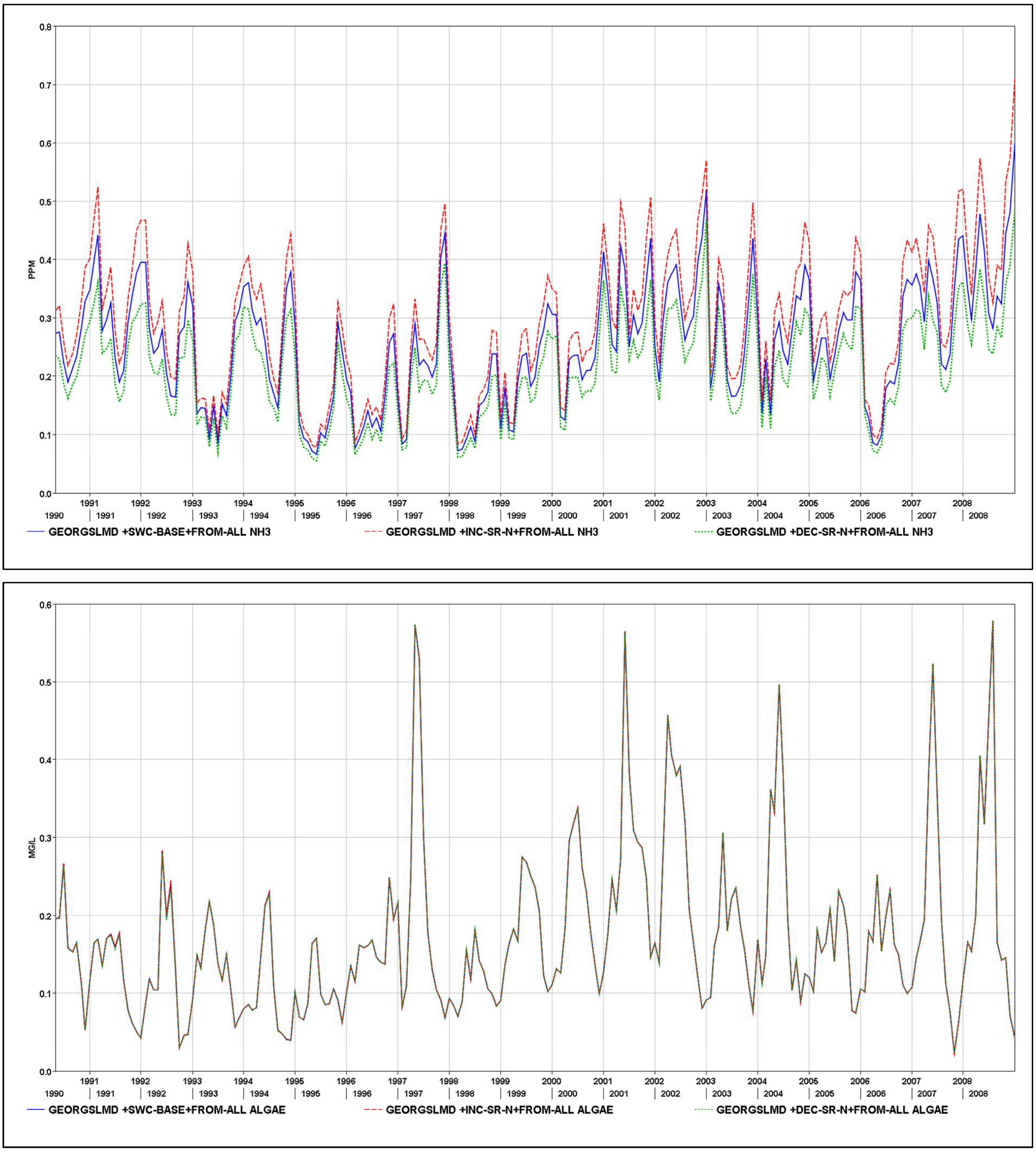


Figure 17-128 Changes in ammonia and chl-a/algae in Georgiana Slough in the scenario changing Sac Regional N-constituents.

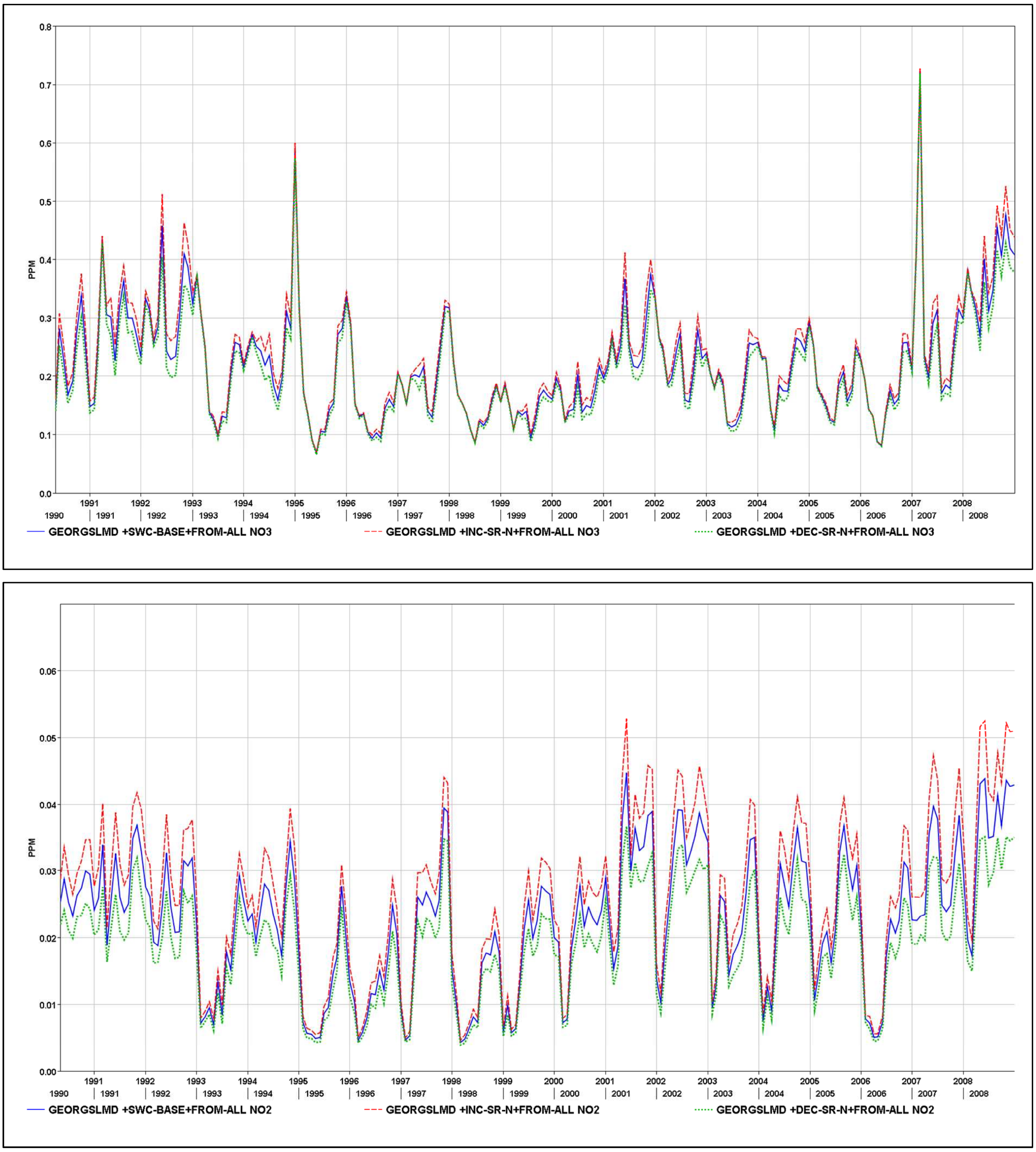
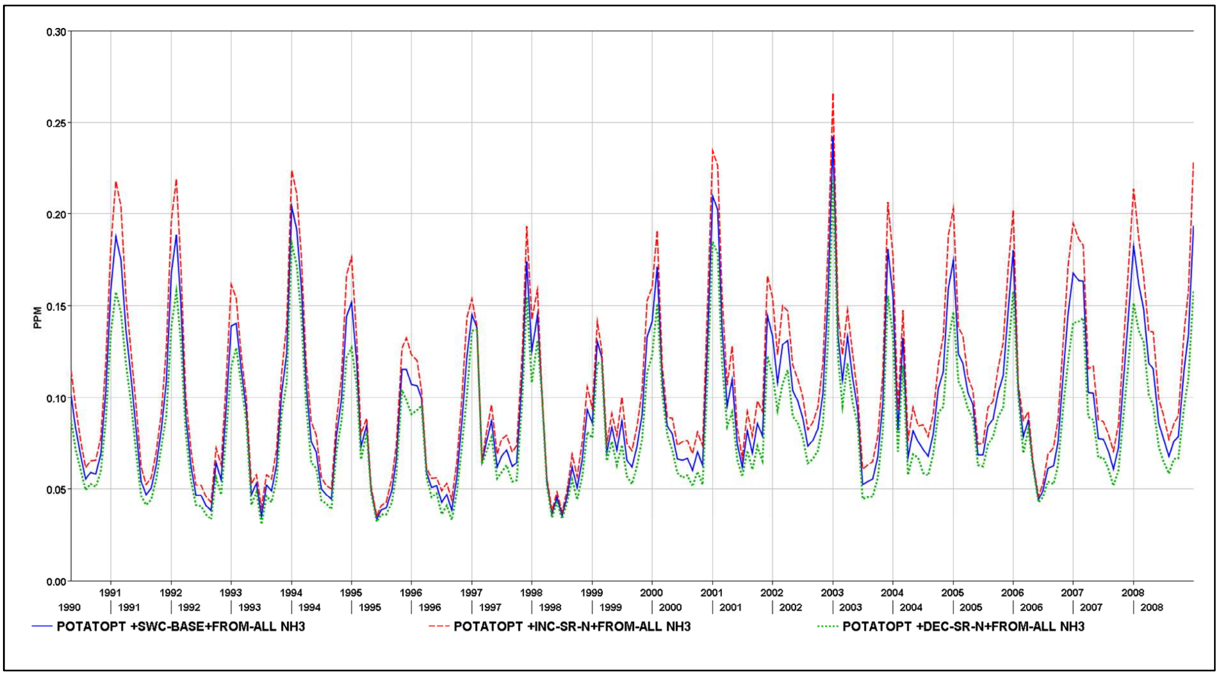


Figure 17-129 Changes in nitrite and nitrate in Georgiana Slough in the scenario changing Sac Regional N-constituents.



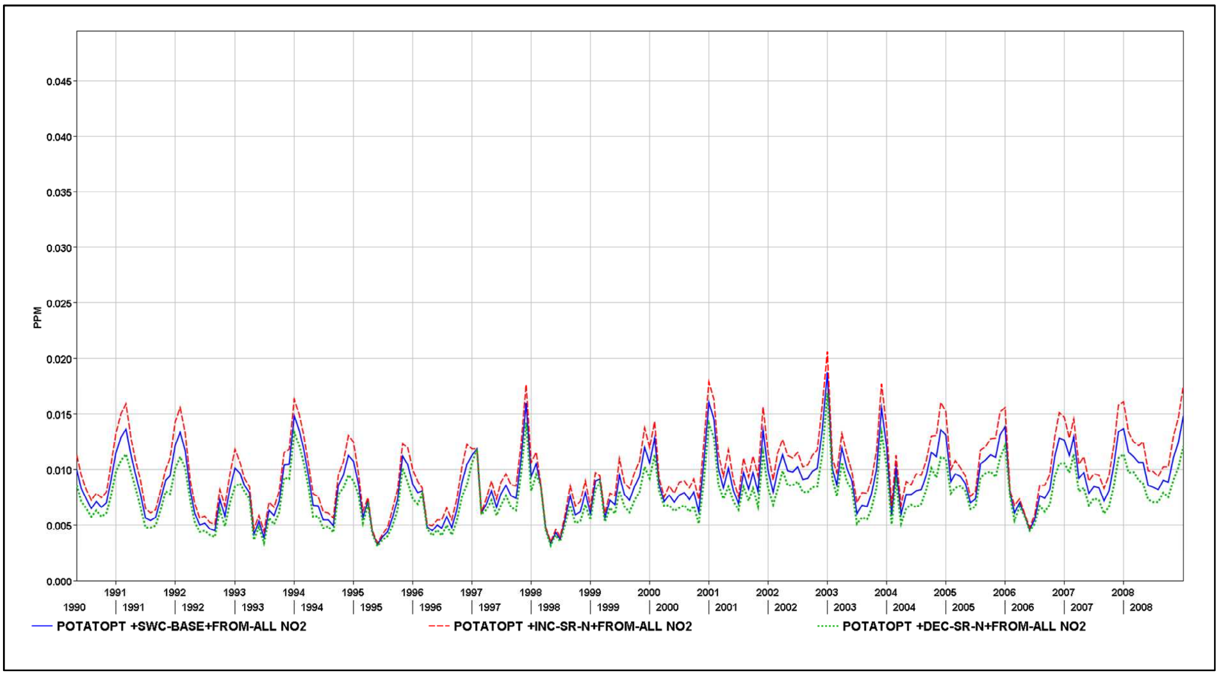


Figure 17-130 Changes in ammonia and nitrite at Potato Point in the scenario changing Sac Regional N-constituents.

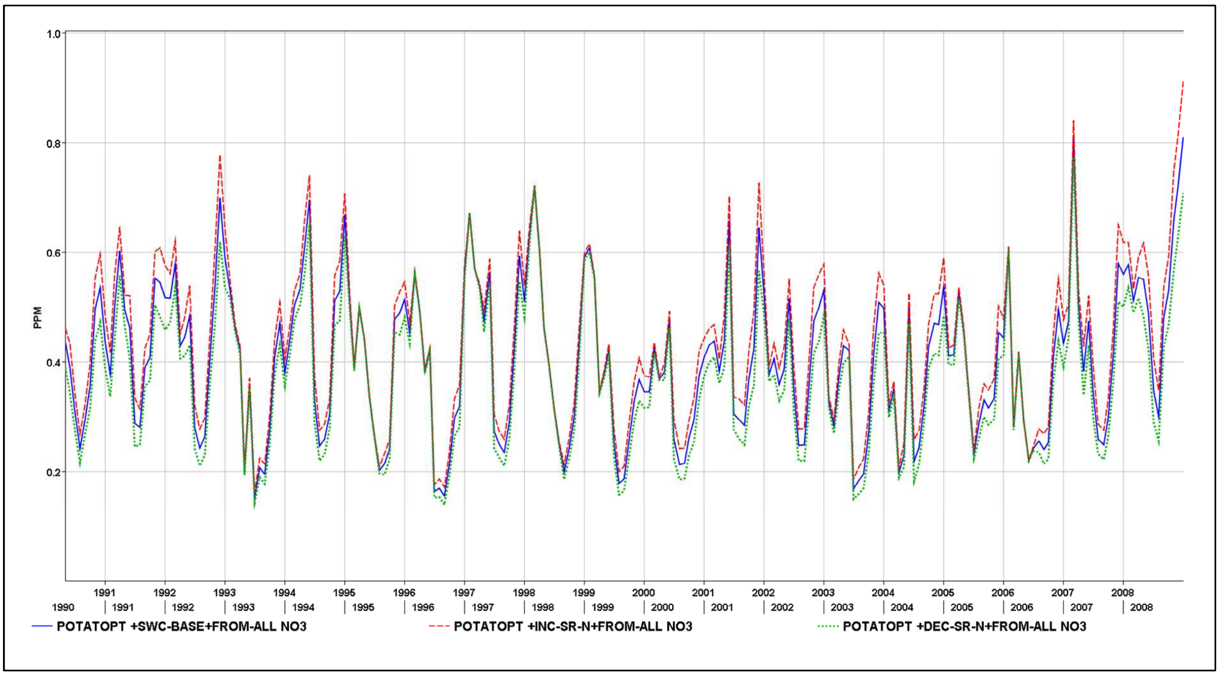
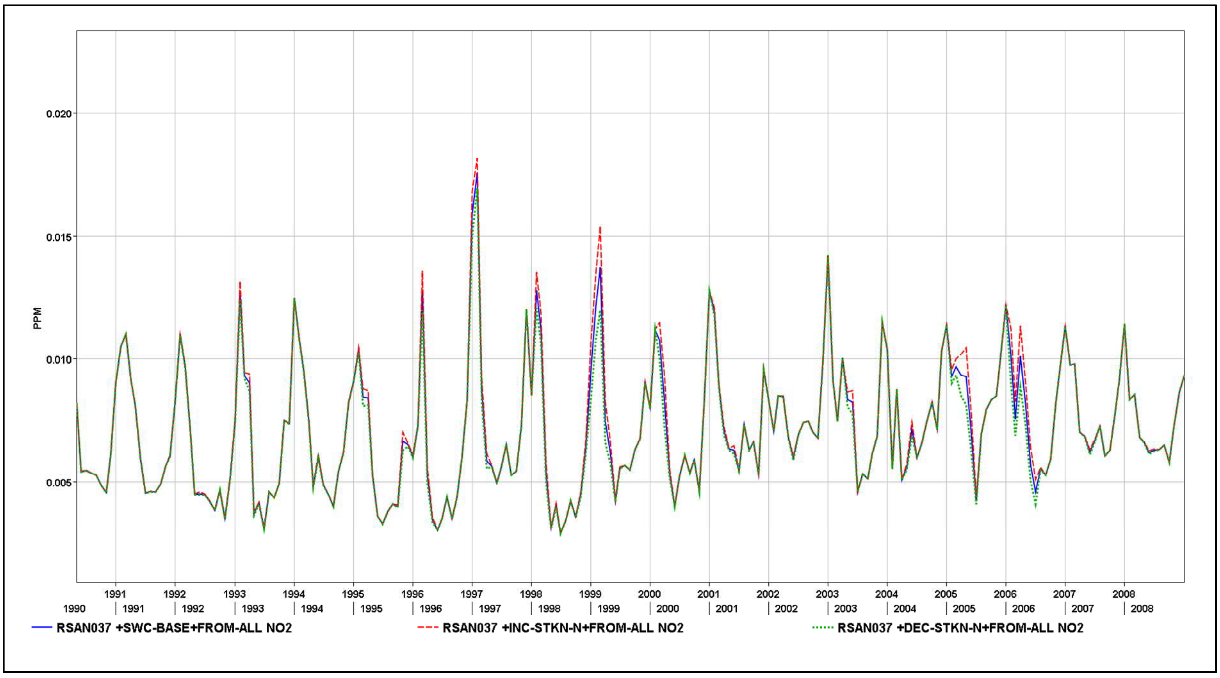


Figure 17-131 Changes in nitrate at Potato Point in the scenario changing Sac Regional N-constituents.



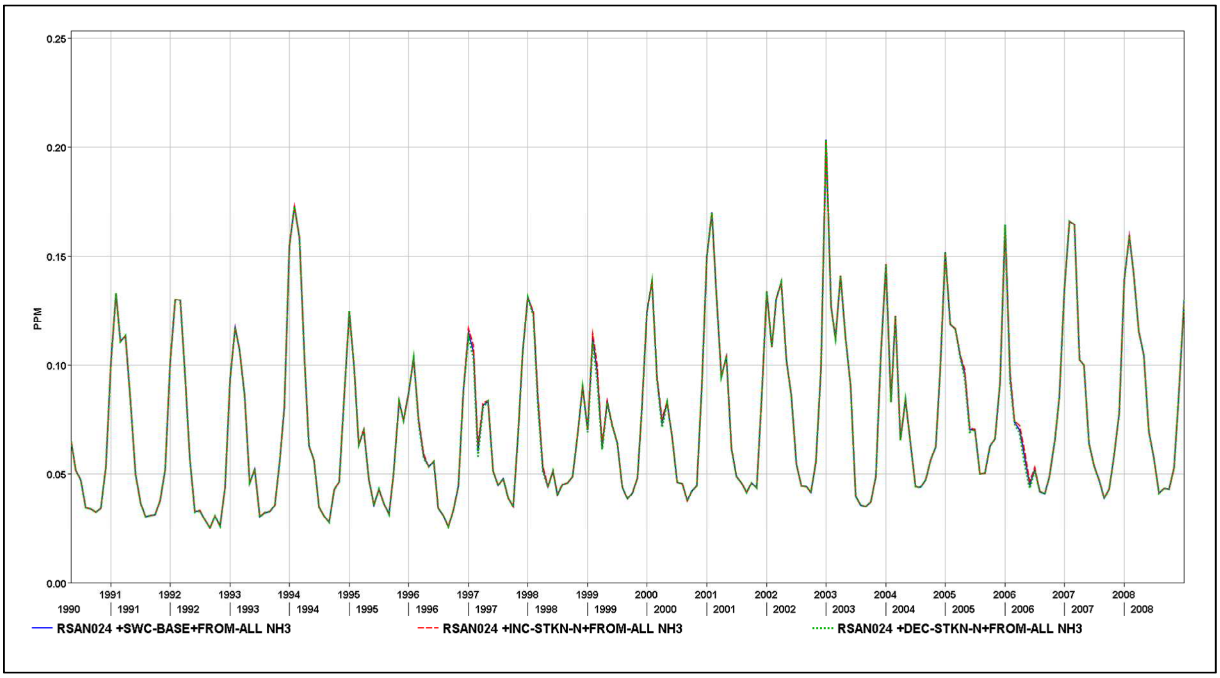
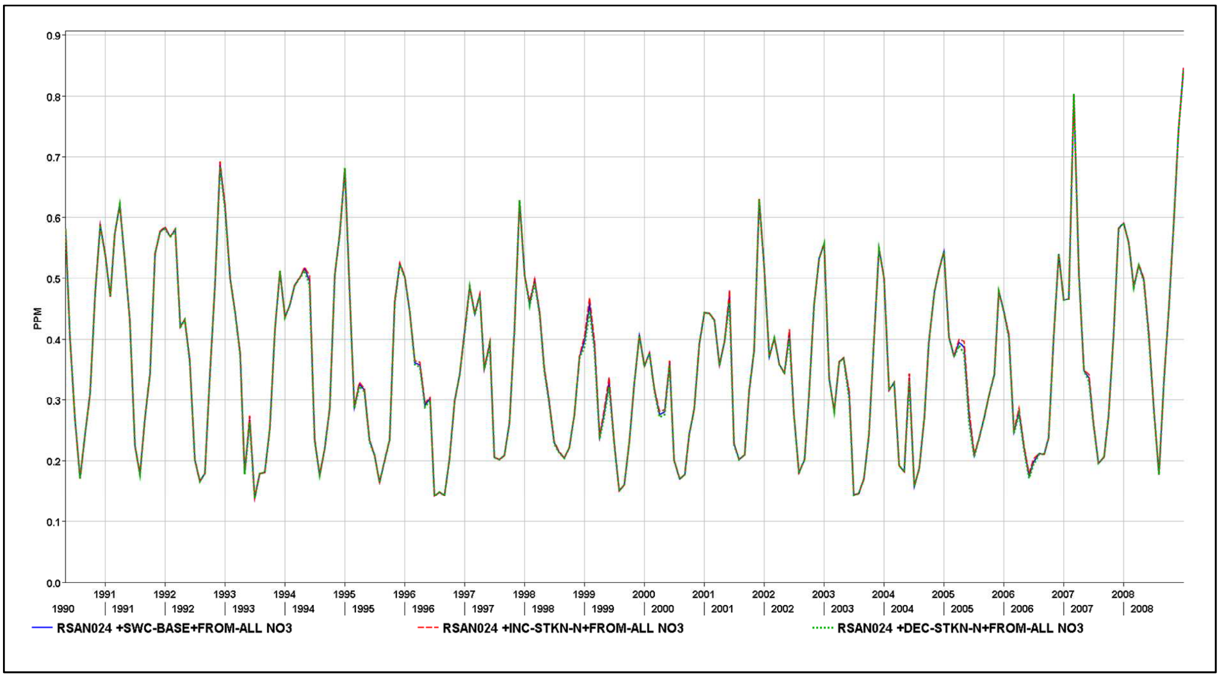


Figure 17-132 Nitrite concentration at RSAN037and ammonia at RSAN024 downstream of the Stockton WWTP.



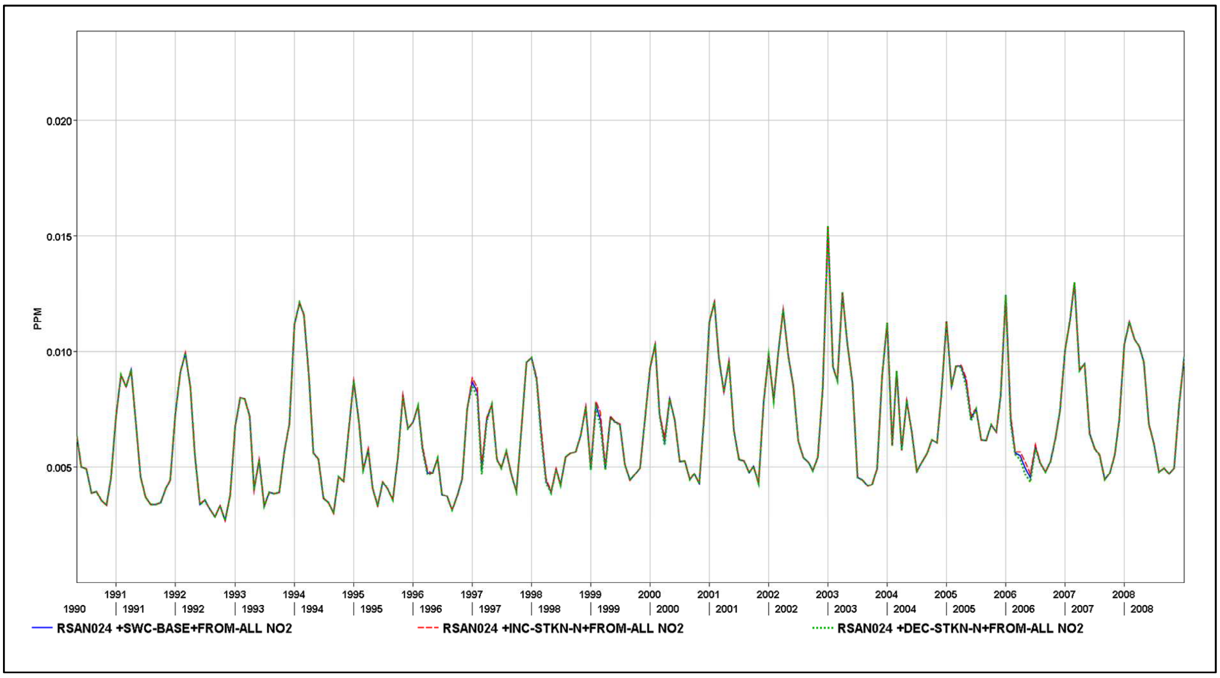


Figure 17-133 Nitrate and nitrite concentrations at RSAN024 downstream of the Stockton WWTP.

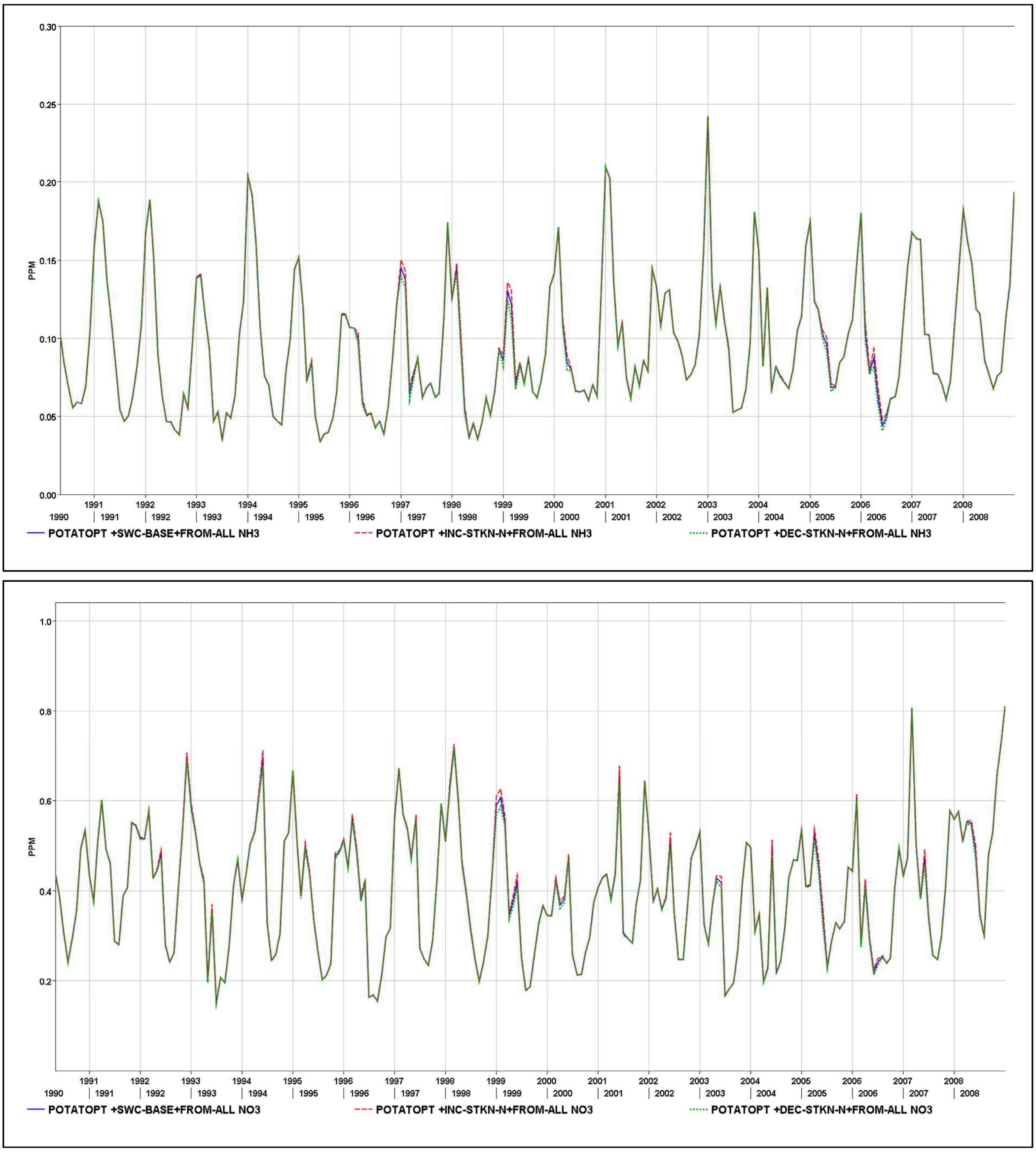
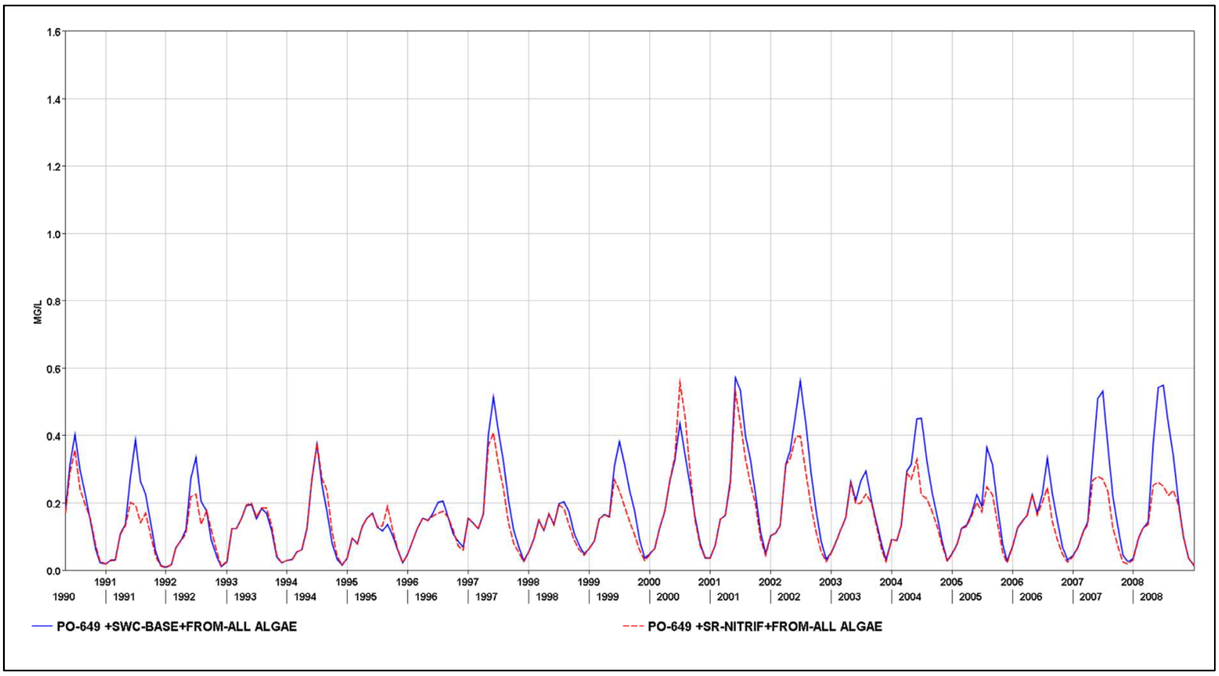


Figure 17-134 Ammonia and nitrate concentrations at Potato Point downstream of the Stockton WWTP.



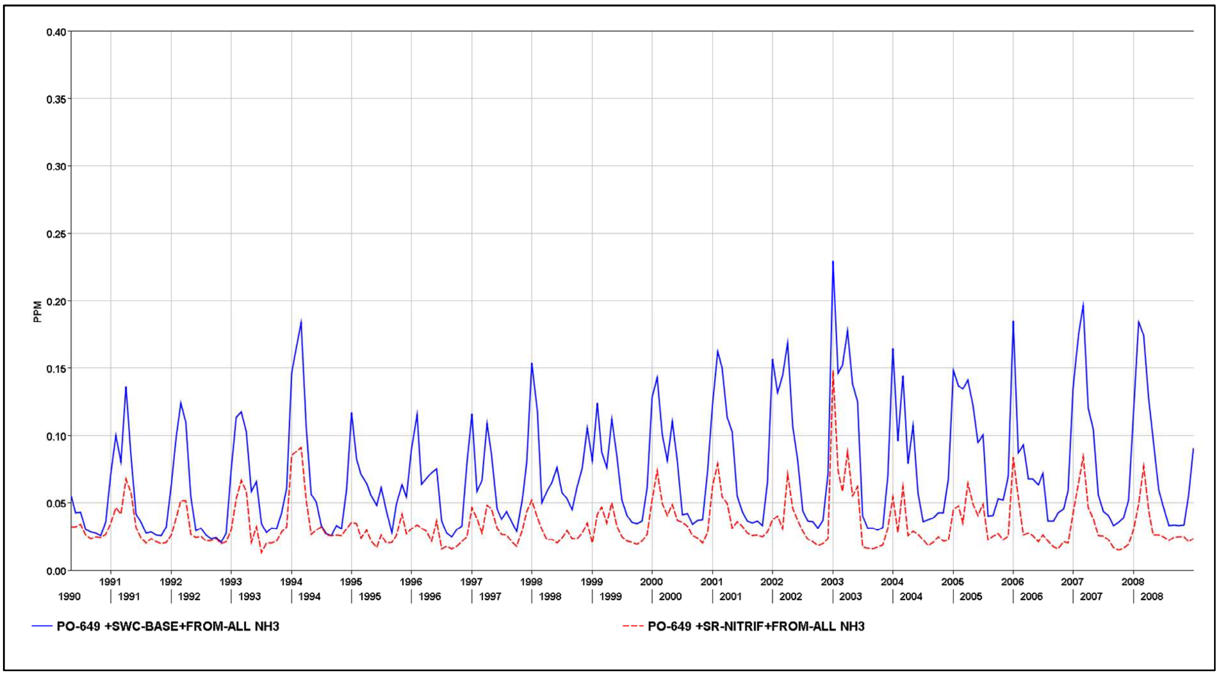


Figure 17-135 Chl-a/algae and ammonia concentrations at Point Sacramento for the Sac Regional Nitrification scenario.

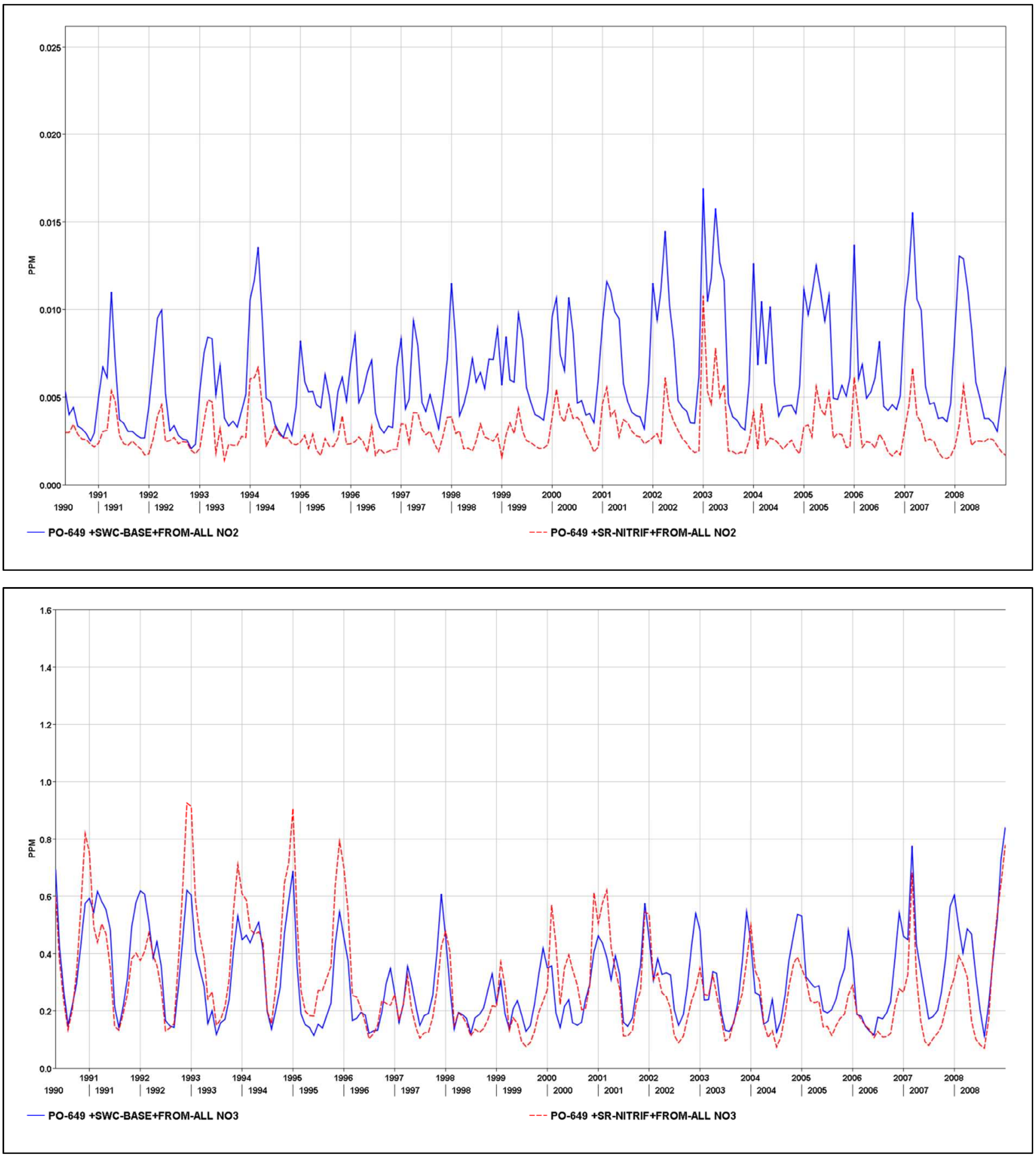
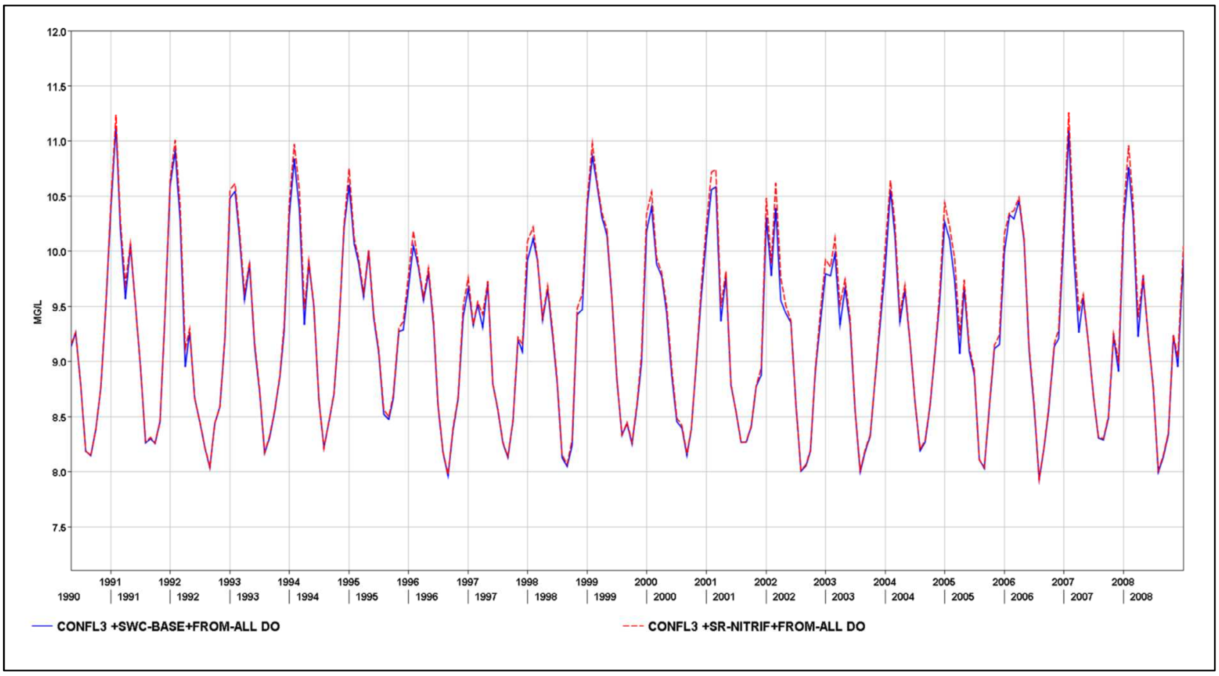


Figure 17-136 Nitrite and nitrate concentrations at Point Sacramento for the Sac Regional Nitrification scenario.



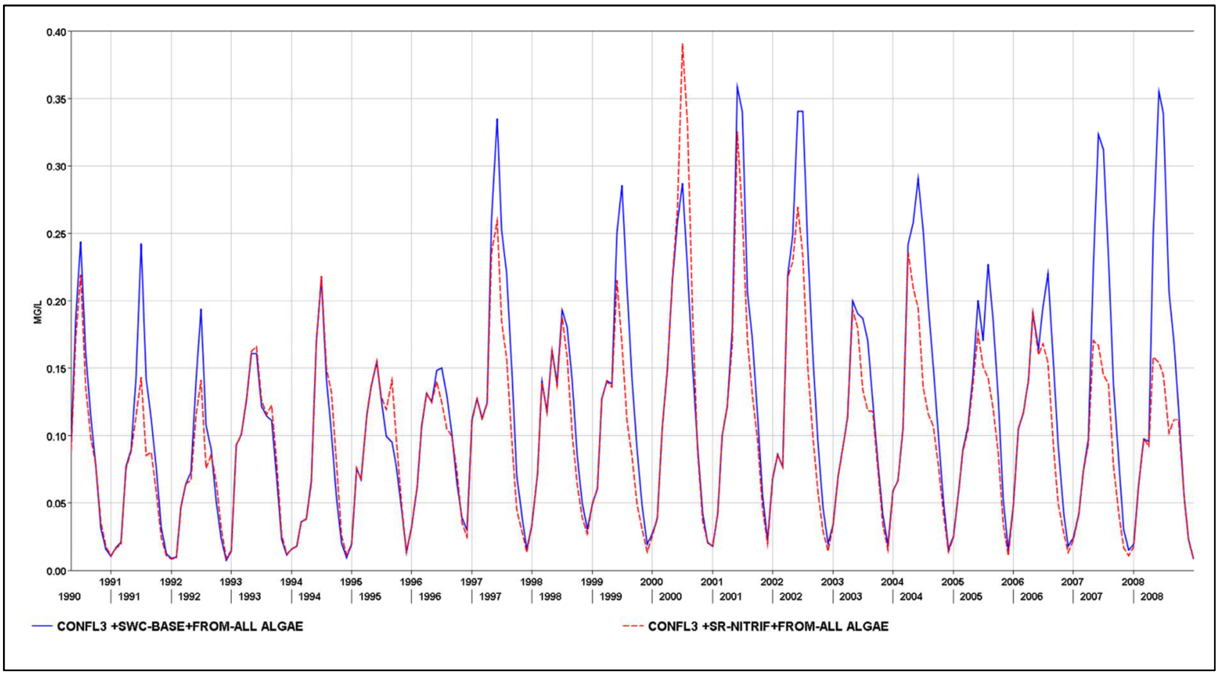


Figure 17-137 DO and Chl-a/algae concentrations at Confluence-3 for the Sac Regional Nitrification scenario

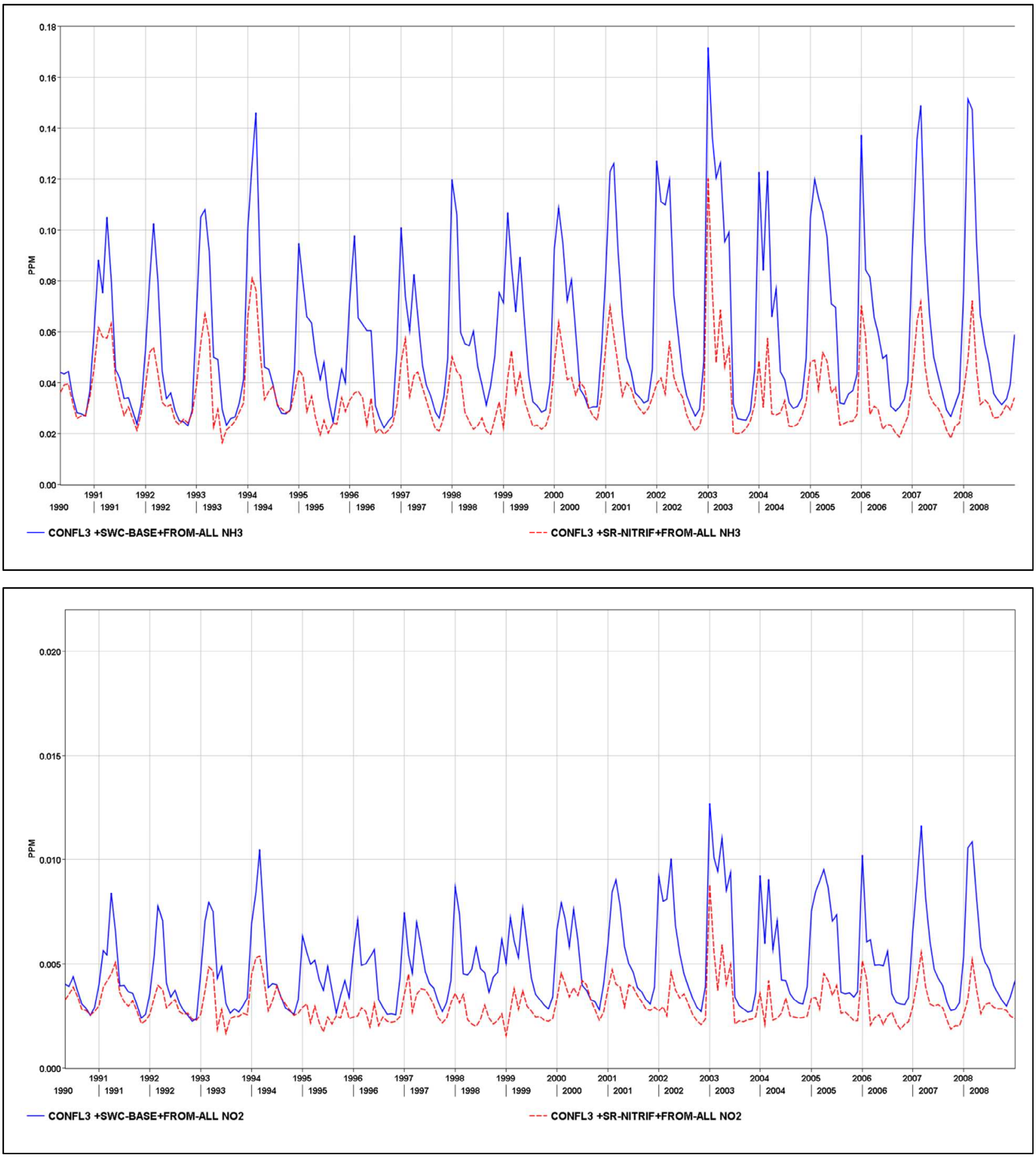


Figure 17-138 Ammonia and nitrite concentrations at Confluence3 for the Sac Regional Nitrification scenario

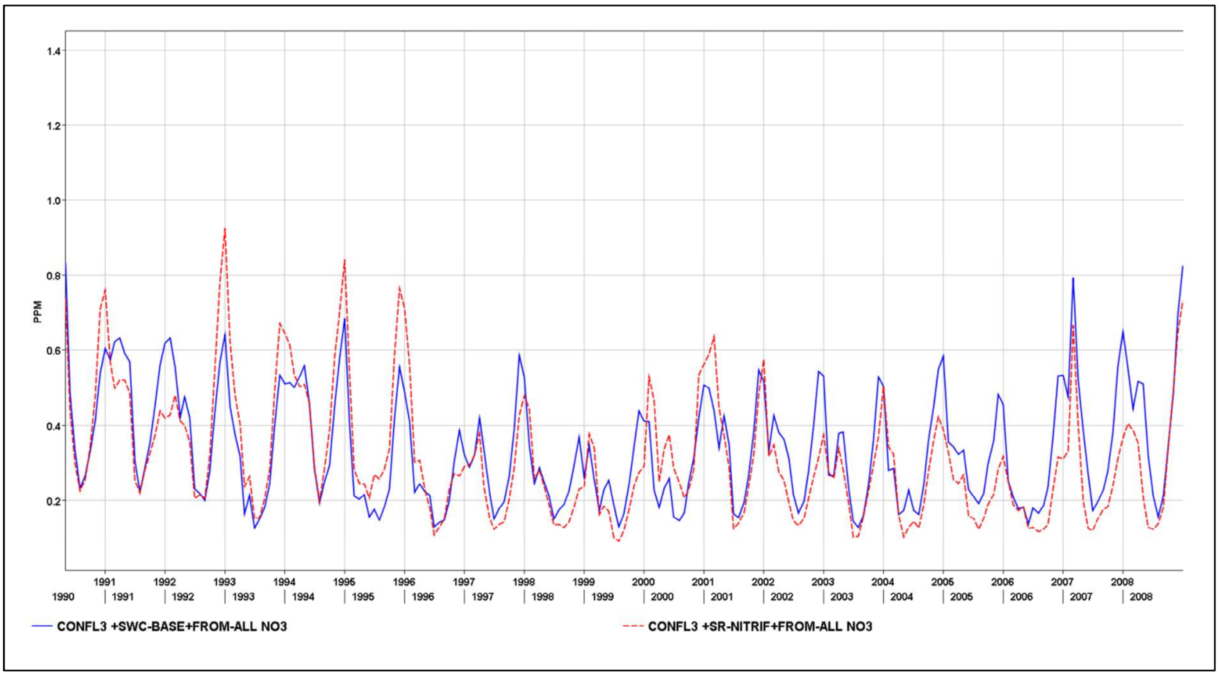


Figure 17-139 Nitrate concentration at Confluence3 for the Sac Regional Nitrification scenario.

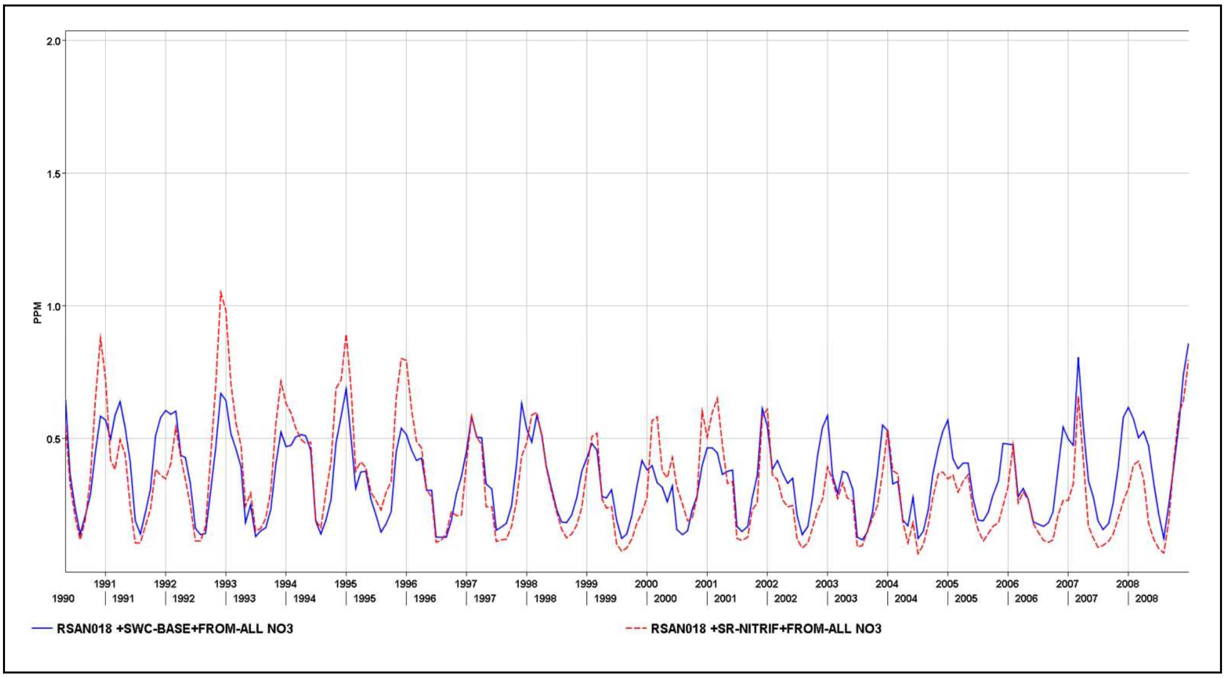
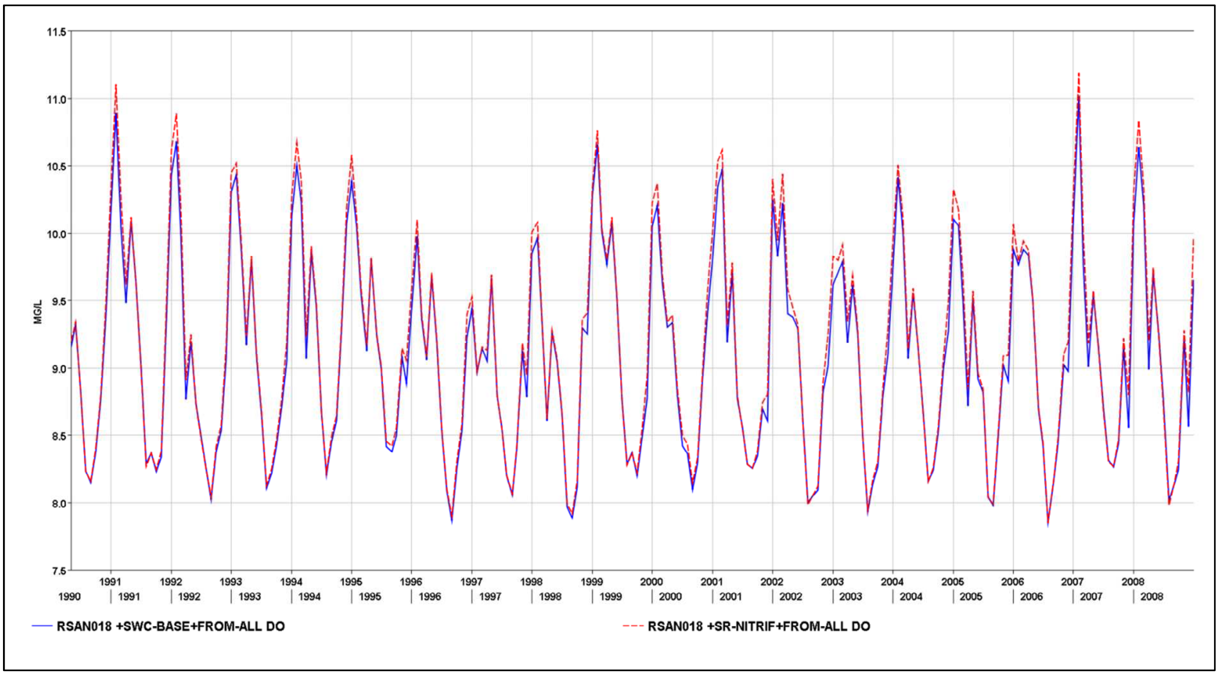


Figure 17-140 Nitrate concentration at Jersey Point for the Sac Regional Nitrification scenario.



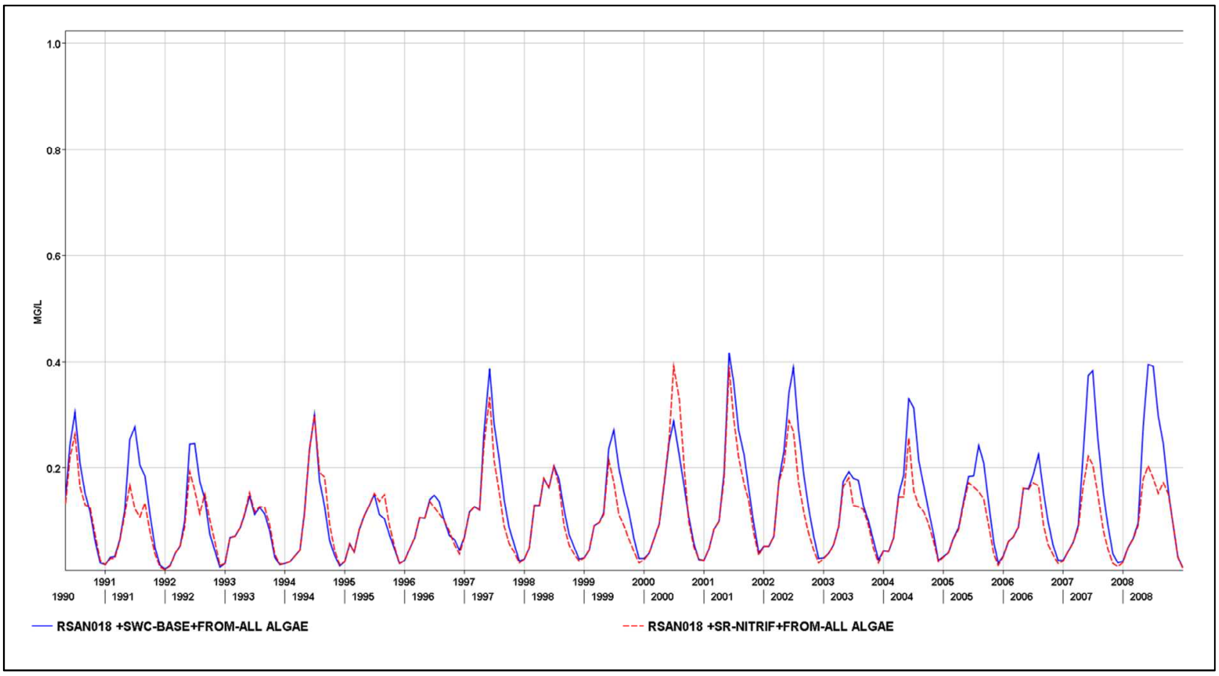
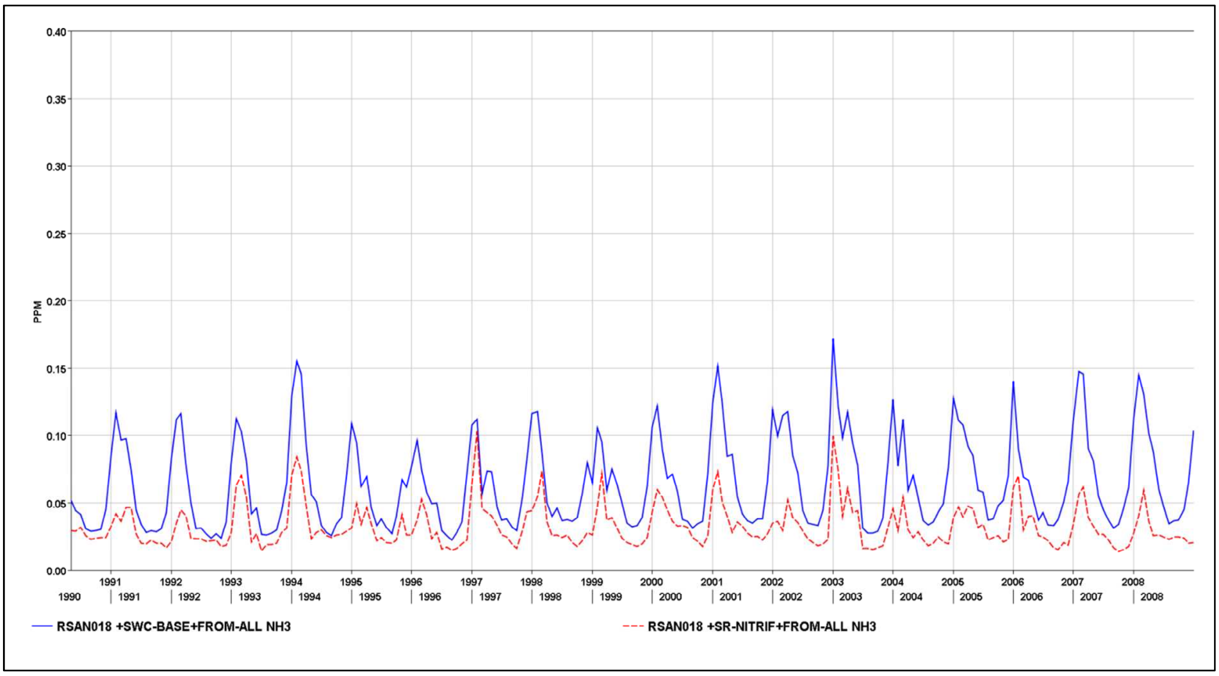


Figure 17-141 DO and Chl-a/algae concentrations at Jersey Point for the Sac Regional Nitrification scenario



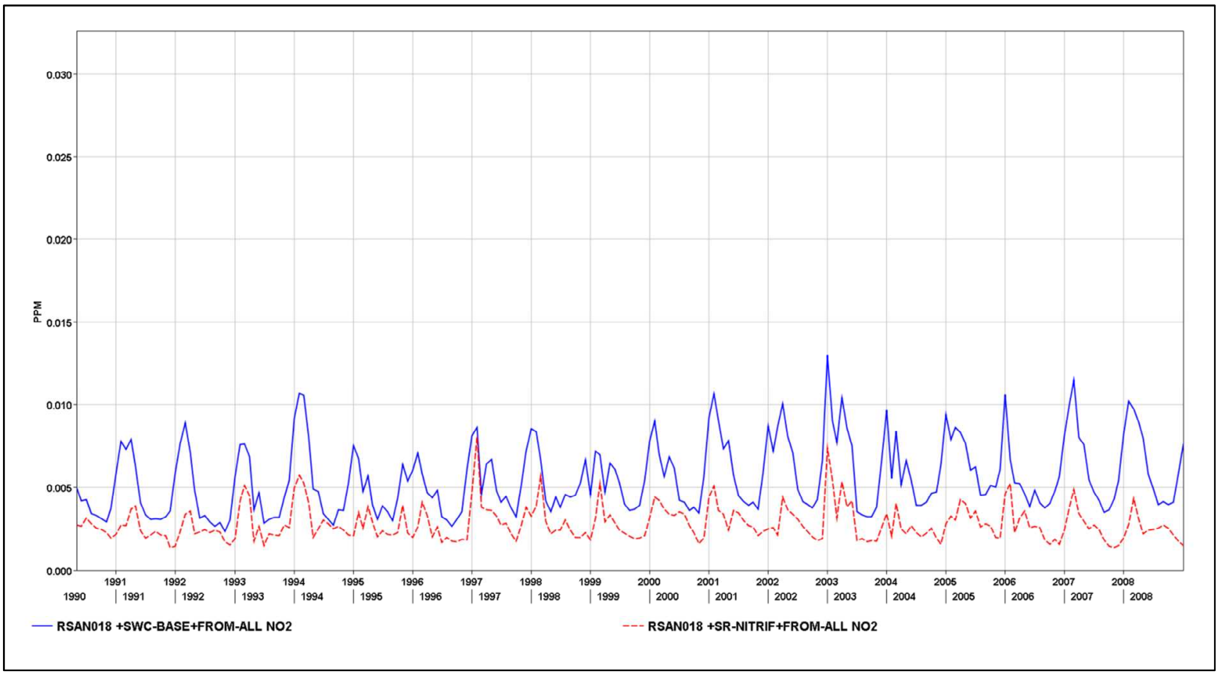
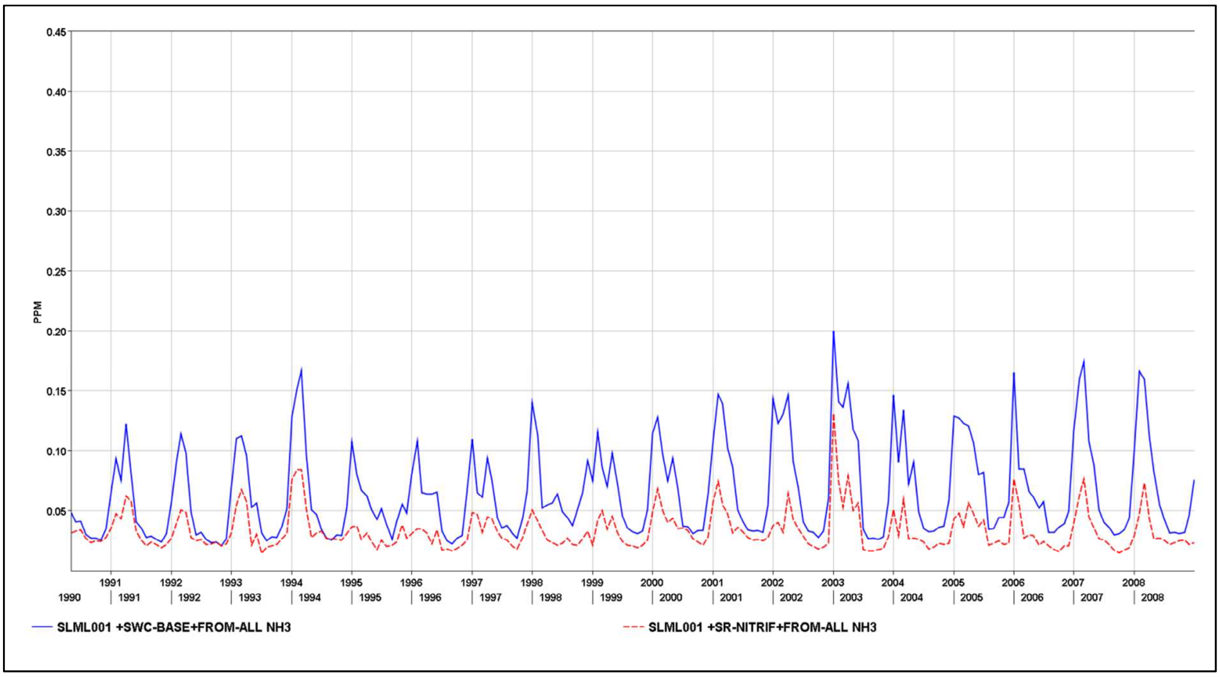


Figure 17-142 Ammonia and nitrite concentrations at Jersey Point for the Sac Regional Nitrification scenario.



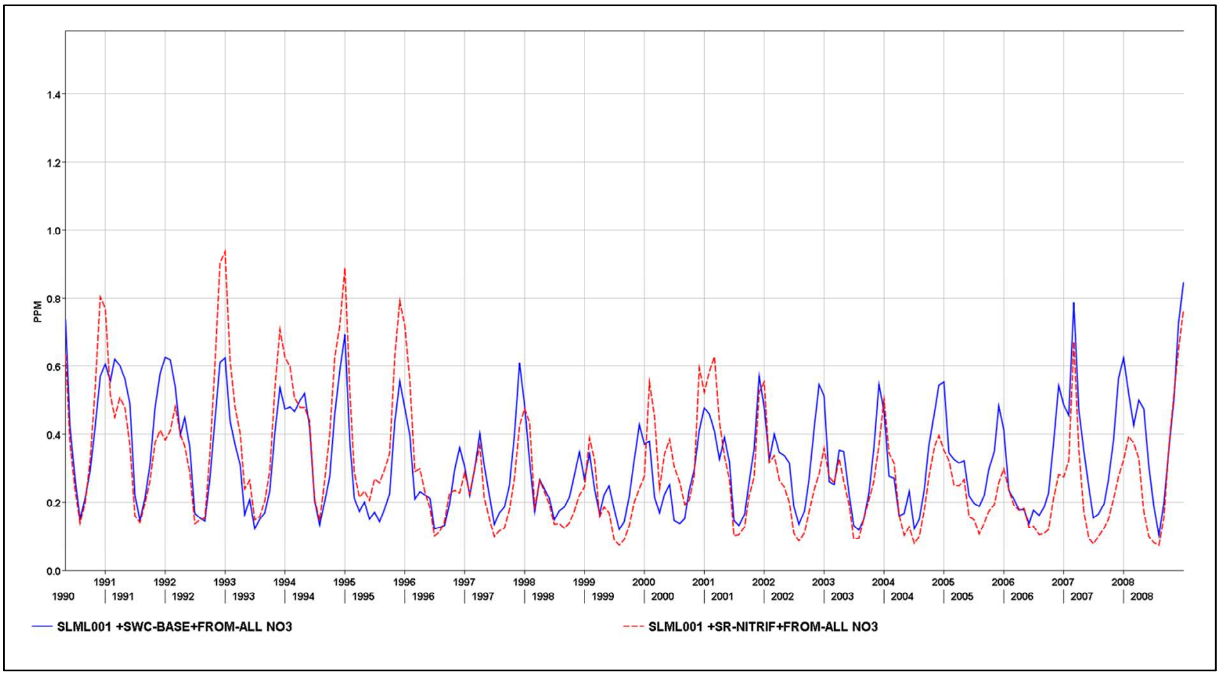


Figure 17-143 Ammonia and nitrate concentration at Suisun Nichols for the Sac Regional Nitrification scenario.

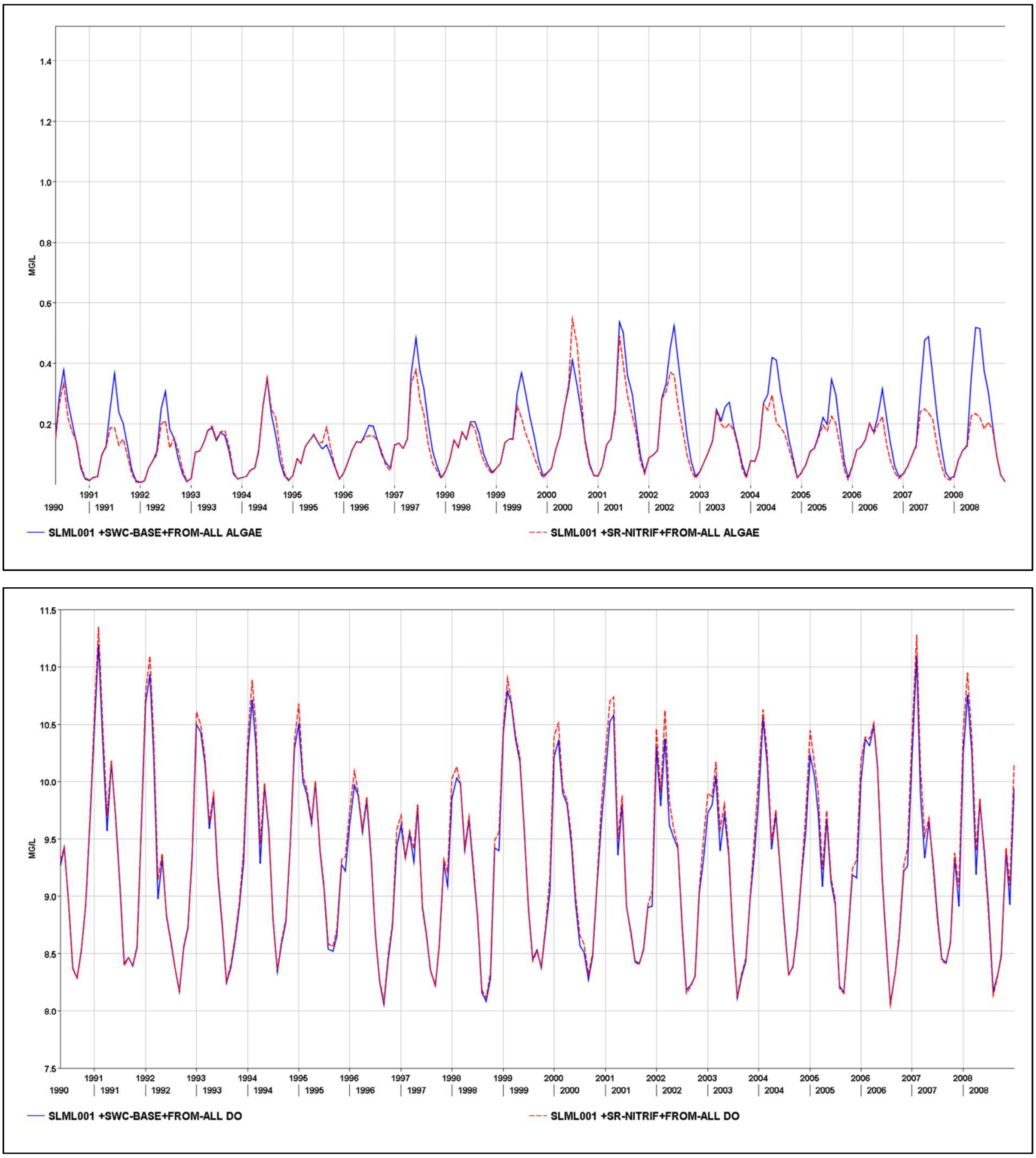


Figure 17-144 Chl-a/algae and DO concentrations at Suisun Nichols for the Sac Regional Nitrification scenario.

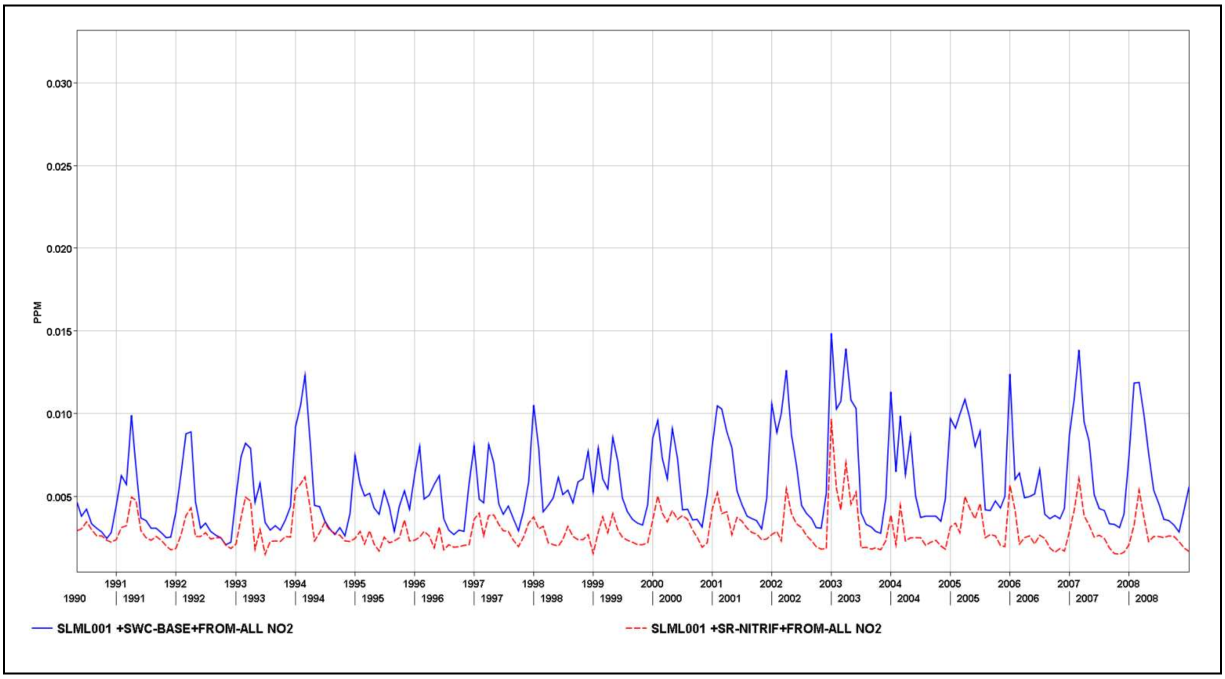


Figure 17-145 Nitrite concentration at Suisun Nichols for the Sac Regional Nitrification scenario.

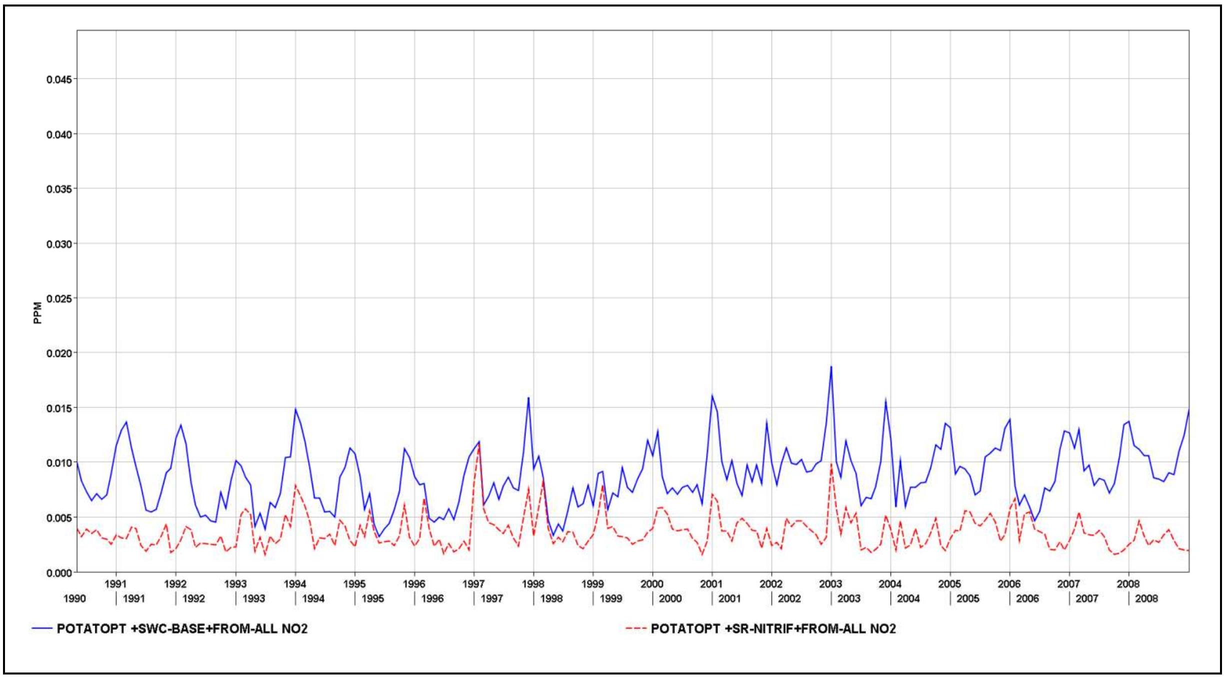
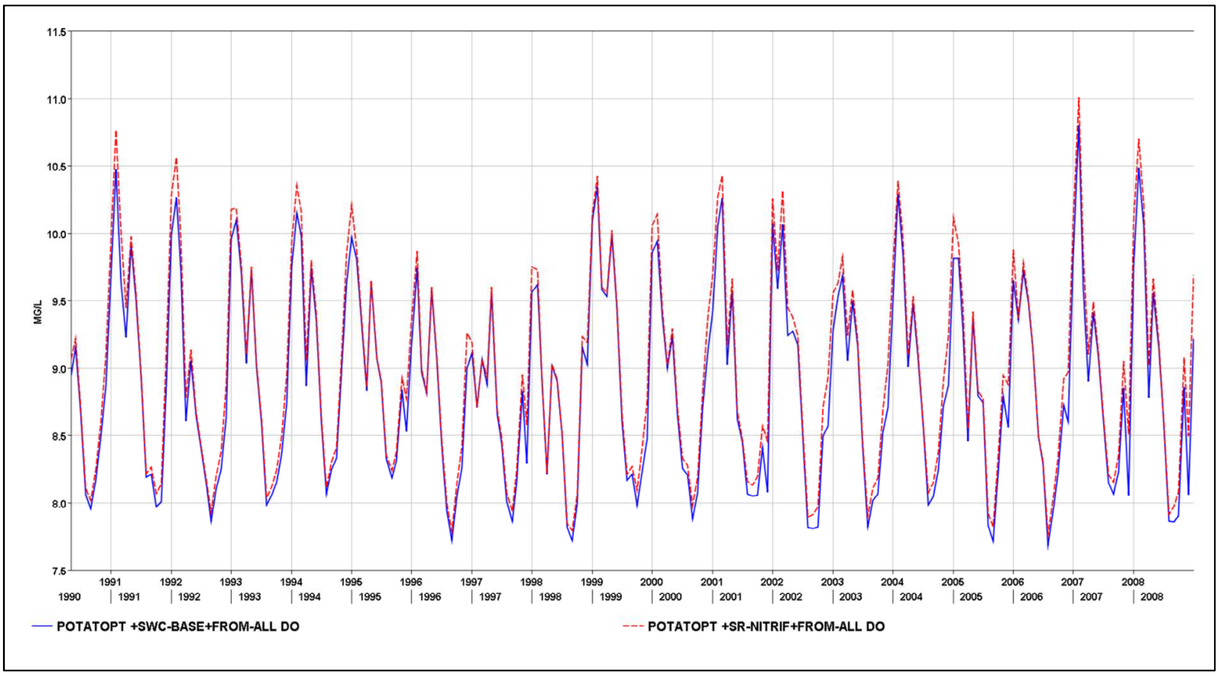


Figure 17-146 Nitrite concentration at Potato Point for the Sac Regional Nitrification scenario.



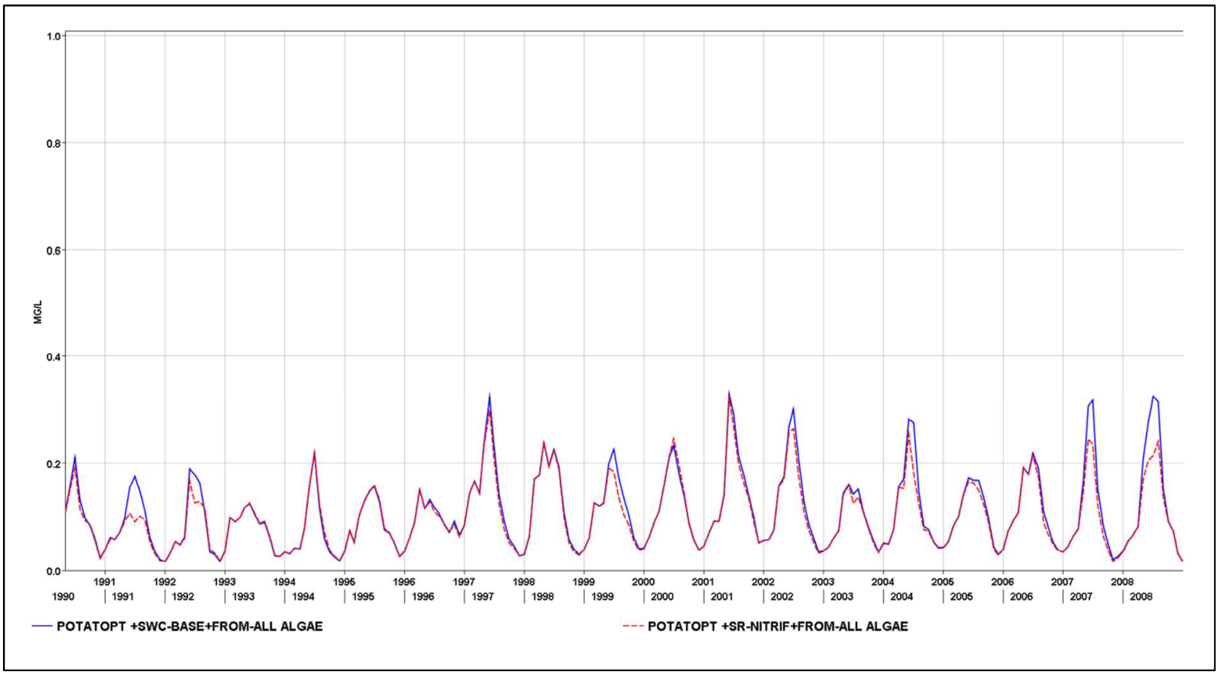


Figure 17-147 DO and chl-a/algae concentrations at Potato Point for the Sac Regional Nitrification scenario.

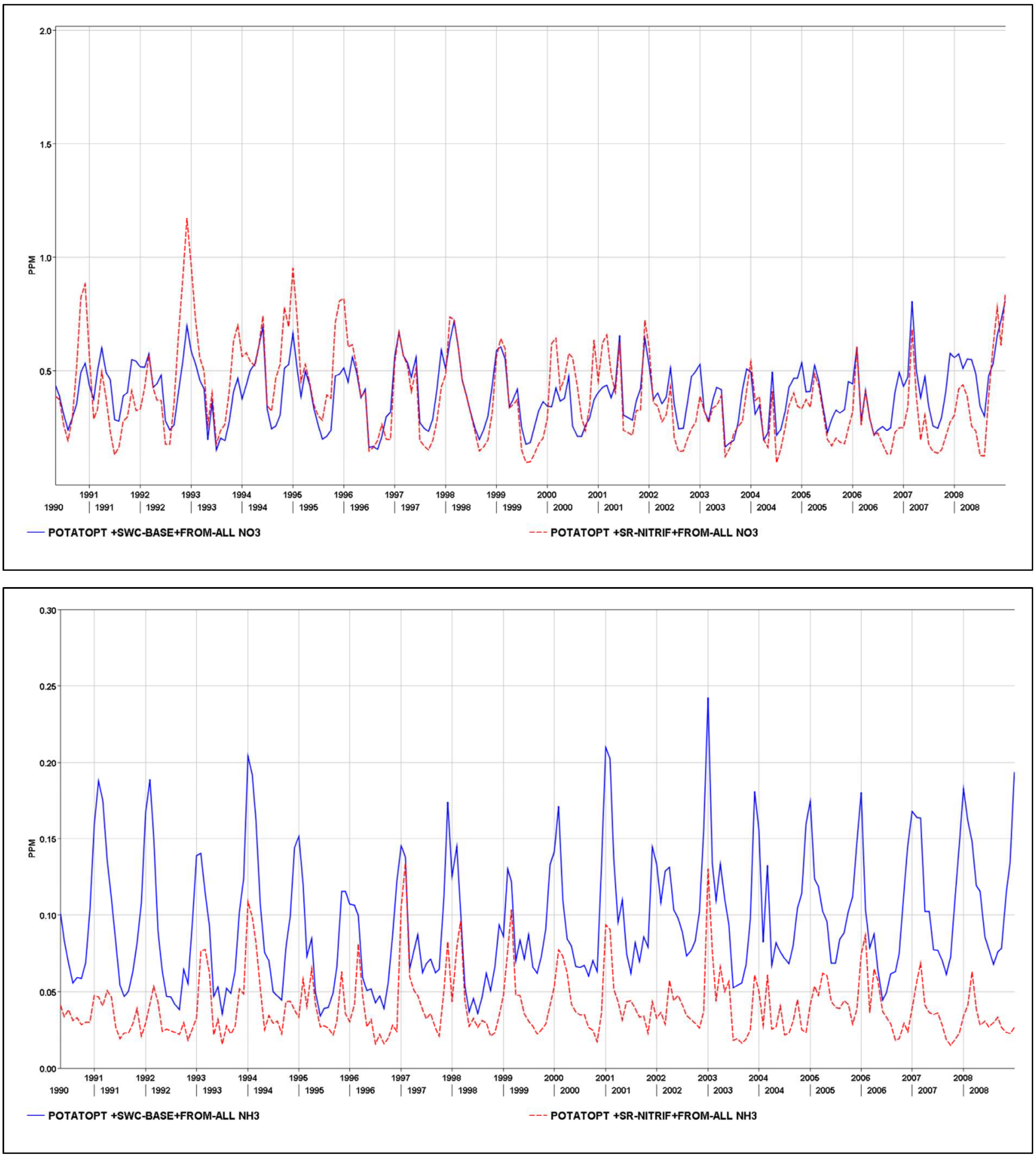


Figure 17-148 Nitrate and ammonia concentration at Potato Point for the Sac Regional Nitrification scenario.

17.12 Estimating Mass Loss at the Martinez Boundary in DSM2

The DSM2 water quality module has a concentration boundary condition at the Martinez tidal boundary. A number of the effluent sources of interest, contributing ammonia and the other nutrients to the Delta, lie within Suisun Bay and the Carquinez Strait. Outgoing tides transport water quality constituents from these sources down past the Martinez boundary and out of the model domain. In the physical system, these constituents would flow back into areas upstream of Martinez on incoming tides, but as the model boundary is typically formulated in DSM2 QUAL, this mass does not return. The result is a loss of mass at the Martinez boundary which has the potential to significantly alter modeled nutrient concentrations and thus the nutrient dynamics upstream of this boundary. Because this area is of significant importance to the Delta ecosystem, an estimate is needed of the magnitude of this loss. In addition, the potential exists to alter the Martinez boundary conditions in a subsequent model run to reintroduce this mass on incoming tides.

The RMA2/RMA11 hydrodynamic and water quality models, described in detail in the next section, were run for a full Bay-Delta geometry (Figure 1) to provide an estimate of the expected constituent mass which should be returning on the incoming tide at the Martinez DSM2 boundary. The simulations were performed for low (3,000-4,000 cfs) and moderate (11,000-16,000 cfs) Net Delta Outflow (NDO) conditions. The simulations specifically examined a discharge from the CCCSD outfall located near Martinez (Figure 17-149) as CCCSD has the largest effluent flow in this region. The model, computations were used to estimate the constituent loss at this boundary condition location and to estimate the need to modify the DSM2 Martinez constituent boundary conditions in order to reintroduce the constituent mass on incoming tides.

17.12.1 RMA Model Representation

The RMA model of the Bay-Delta, shown in Figure 17-149, extends from the Golden Gate to the confluence of the American and Sacramento Rivers, and to Vernalis on the San Joaquin River. San Francisco Bay and Suisun Bay regions, and the Sacramento – San Joaquin confluence area are represented using a two-dimensional (2-D) depth-averaged approximation. The Delta channels and tributary streams are represented using a one-dimensional (1-D) cross-sectionally averaged approximation. The Sacramento-San Joaquin confluence area was refined with the addition of 2-D elements representing marsh areas in Sherman Lake, between Middle Slough and New York Slough and other marsh areas in the vicinity. A closer view of Suisun Bay and the western and central Delta is shown in Figure 17-150.

Detail representing the CCCSD outfall includes mesh refinement around the CCCSD outfall and along the southern shoreline in the vicinity of the outfall. These refinements allow more accurate computation of concentration gradients near the outfall, and better representation of the effluent plume along the southern shoreline. The mesh around the outfall, as shown in Figure 17-151 and in Figure 17-152, has been used in previous studies (RMA, 2000) with some minor modifications. The element representing the CCCSD effluent outfall (shown in red in Figure 17-152) is approximately 144 ft (44_m) long by 65 ft (20_m) wide. CCCSD's submerged outfall line is 132 ft (40 m) in length.

The size and shape of elements are dictated by changes in bottom elevation and other hydraulic considerations. Wetting and drying of the tidal mudflats has been represented in sufficient detail to provide a good definition of change in the tidal prism that occurs with change in tidal stage. Aside from the latest grid modifications, bottom elevations and the extent of mudflats are based on NOAA navigation charts, NOAA hydrographic survey data, and aerial photo surveys processed by USGS and Stanford University. The latest addition of marsh areas is based on DWR LiDAR data (DWR, 2007) and aerial photographs. Model bathymetry is shown in Figure 17-153, with a close-up view in the vicinity of the CCCSD outfall shown in Figure 17-154.

Hydrodynamic model operation requires specification of the tidal stage at the Golden Gate and inflow and withdrawal rates at other external boundaries. Flow boundary conditions include the Sacramento River, San Joaquin River, and other rim flows, channel depletions, and exports.

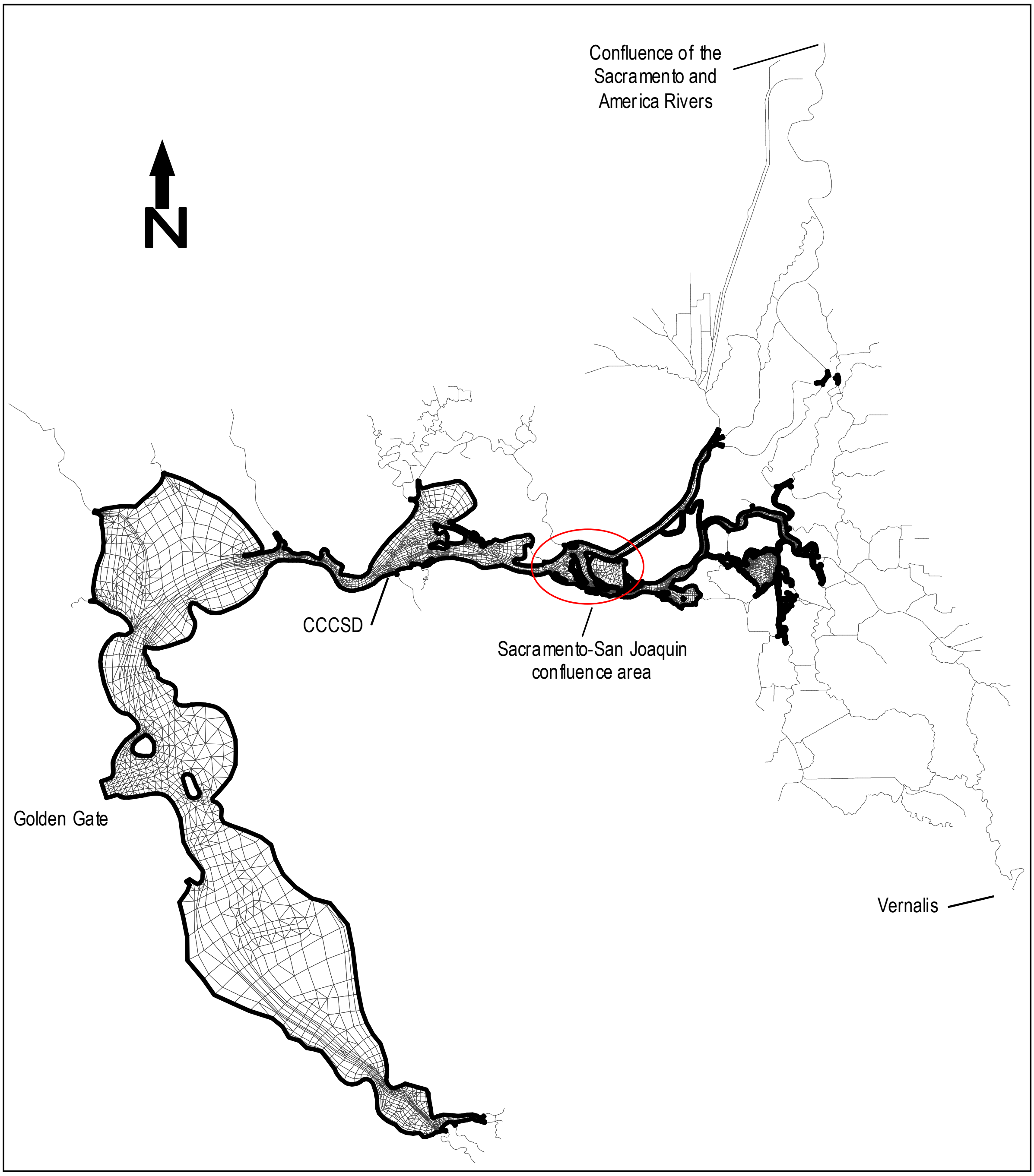


Figure 17-149 Finite element mesh of San Francisco Bay and Delta.

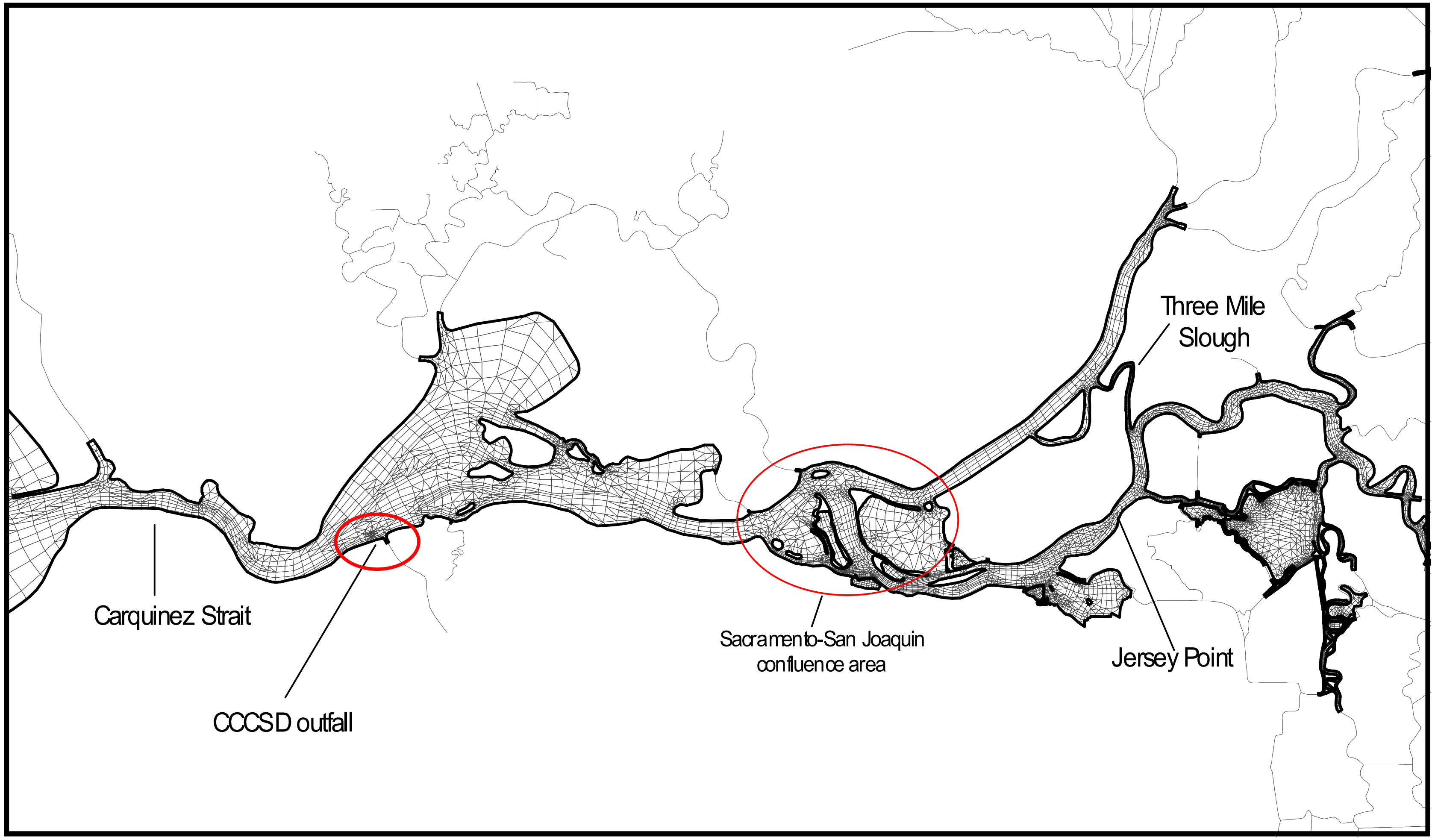


Figure 17-150 Finite element mesh in the vicinity of Suisun Bay and the western and central Delta, with the CCCSD effluent outfall location indicated in red.

Figure 17-151 RMA2/RMA11 Bay-Delta network used to examine effect of Martinez water quality boundary condition location.

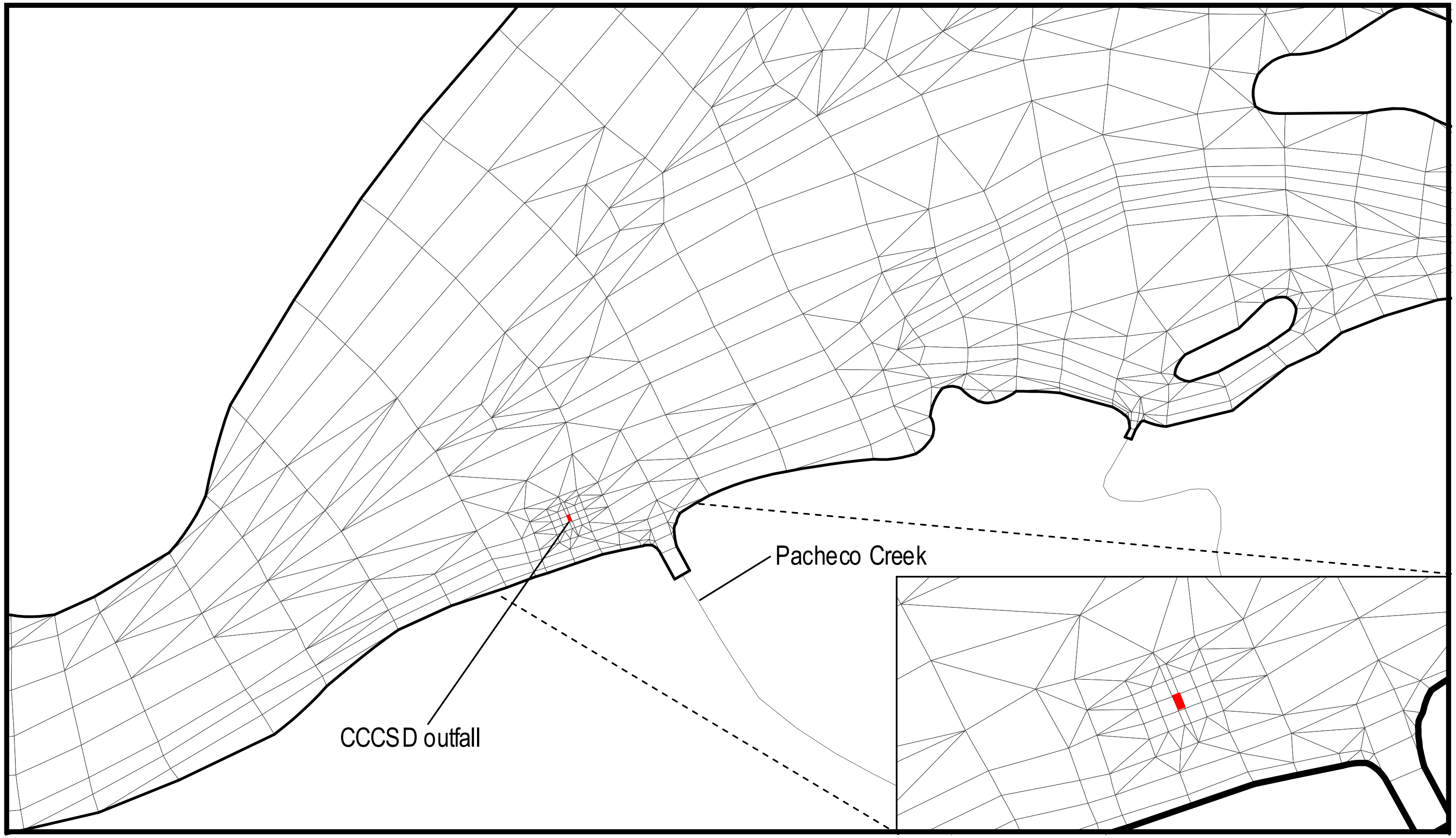


Figure 17-152 Finite element mesh in the vicinity of the CCCSD outfall. Expanded view shows outfall element in red.

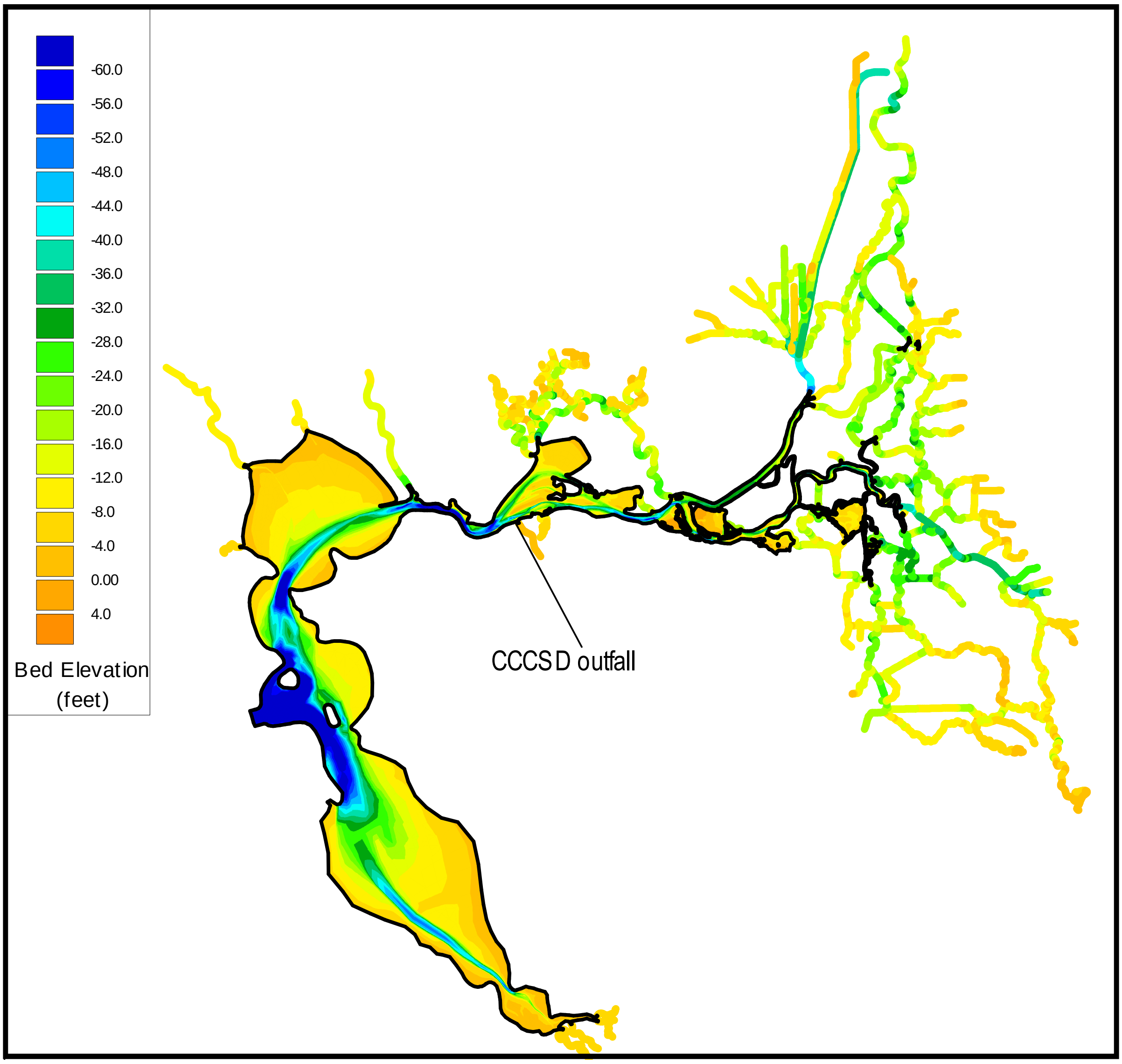


Figure 17-153 Model bathymetry contours.

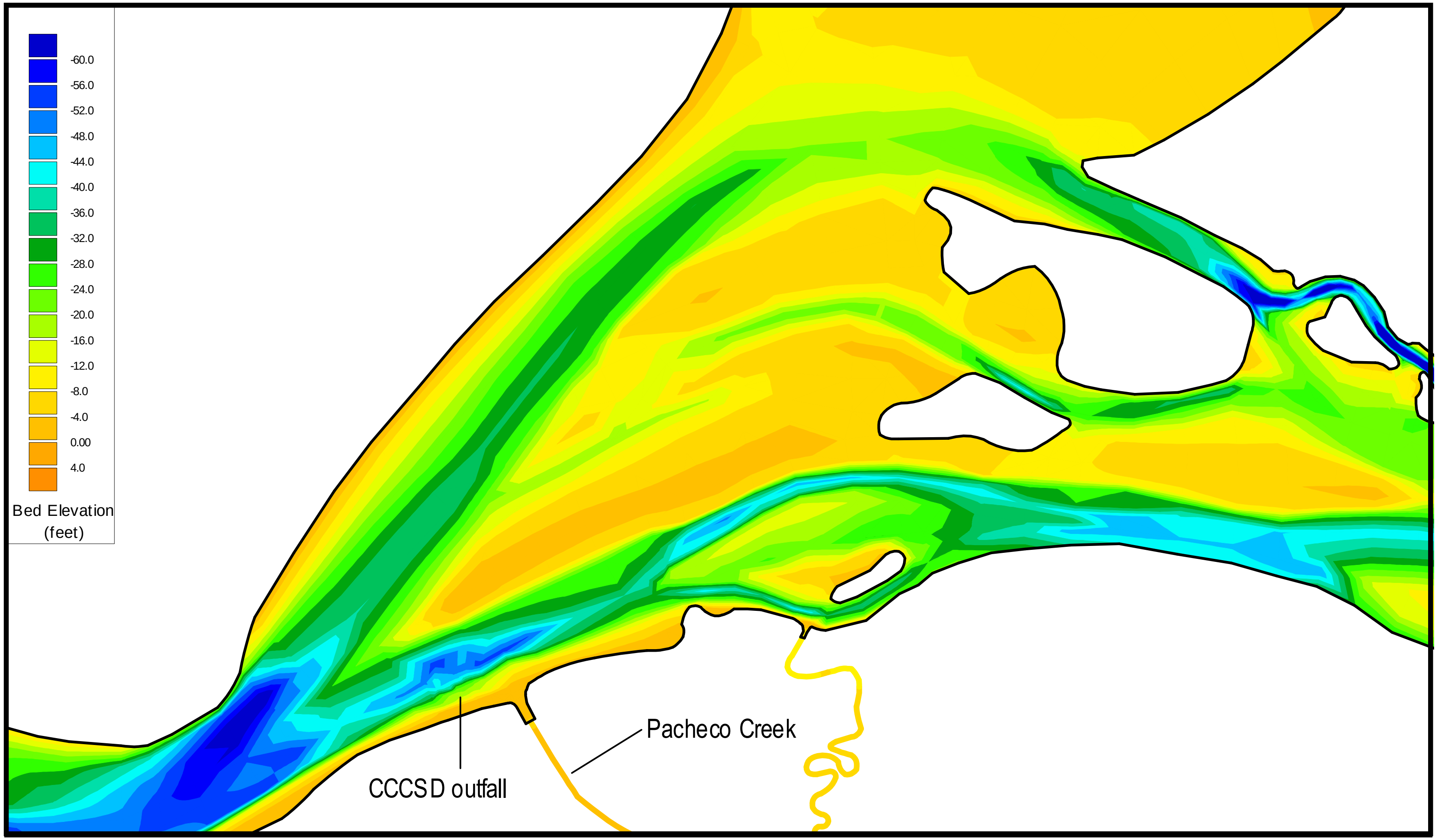


Figure 17-154 Model bathymetry contours in the vicinity of the CCCSD outfall.

17.12.2 Martinez Boundary Condition - Tracer Simulations

The RMA2/RMA11 hydrodynamic and water quality models were run for a full Bay-Delta geometry (Figure 17-149) to provide an estimate of the expected constituent mass which should be returning on the incoming tide at the Martinez DSM2 boundary. The simulations specifically examined a discharge from the CCCSD outfall located near Martinez (Figure 17-151). Both conservative and non-conservative (decay constant = 1 /day) tracer types were modeled. The discharge volume simulated for the CCCSD outfall was 42.2 mgd, or 1.849 m3/sec. Tracer concentration for the discharge was set to 100 g/m3 so results can be interpreted as percent effluent and used to determine the percent of CCCSD effluent that returns to the system on an incoming tide for a model boundary set at Martinez.

Two periods were simulated, one at low net Delta outflow (3,000-4,000 cfs) and one at moderate net Delta outflow (11,000-16,000 cfs). The 29-day period of August 16 through September 13, 2002 represents 10% net Delta outflow exceedance ranking and the April-May 2002 period represents the 50% exceedance ranking. To compute these flow rankings, a 29-day running average of year 2000 – 2006 net Delta outflows, calculated from Dayflow[20] net Delta outflow data, was computed. The averaged outflows were then sorted and ranked based on the percent of time a flow exceeds all other net Delta outflows during that period.

NOAA tide data at San Francisco was used to set the tidal boundary at the Golden Gate. The tide data were smoothed using a five-point moving average, and shifted to NGVD 29 vertical datum. Flow data from the Interagency Ecological Program (IEP) database [21] and Dayflow were used to set flow boundaries for the Sacramento River, San Joaquin River, Yolo Bypass, Mokelumne and Cosumnes Rivers, miscellaneous eastside flows (including Calaveras River, French Camp Slough and other minor tributaries), and exports. USGS flow data[22] were used to set Napa River flows. DWR's computed monthly average channel depletions/precipitation data[23] were used to represent agricultural influences.

Initial tracer simulation results were extracted at several locations from Martinez to the CCCSD outfall. Further tracer runs were performed with and without a zero concentration boundary condition at Martinez implemented in the RMA models.

[20] http://iep.water.ca.gov/dayflow/index.html

[21] http://www.iep.water.ca.gov/dss/all/

[22] http://waterdata.usgs.gov/nwis/dv/?site_no=11458000

[23] http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/models/dicu/dicu.cfm

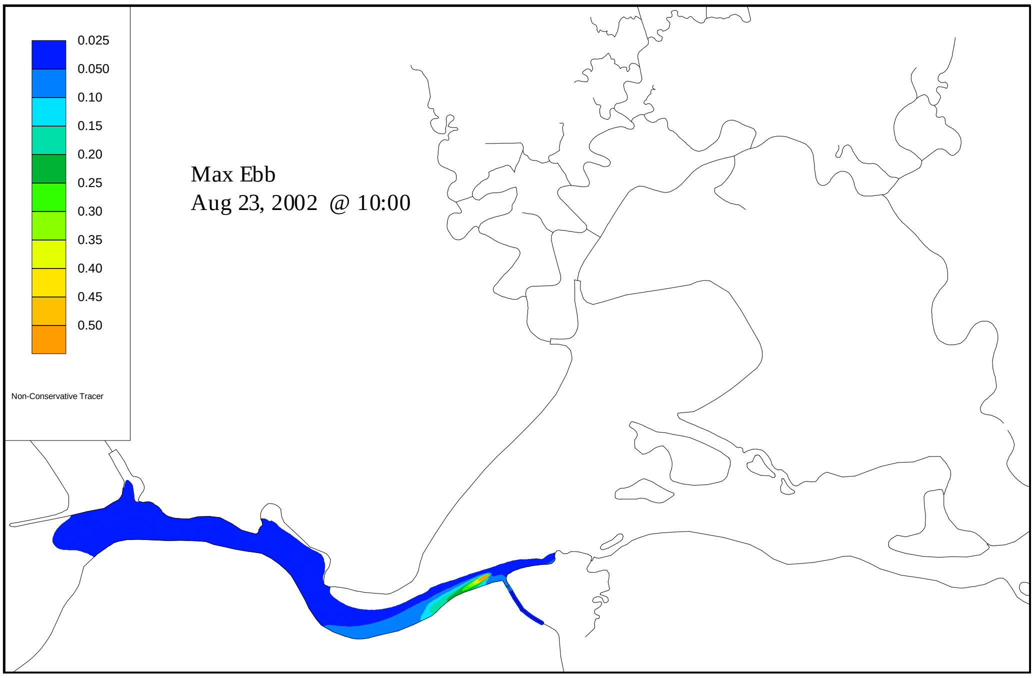
The period August 16 to September 14, 2002 was simulated to examine the tracer loss for low NDO conditions. Figure 17-155, Figure 17-156 and Figure 17-157 present concentration contour plots of the CCCSD tracer for August 23, 2009, after 1 week of simulation. Figure 17-155 shows the CCCSD tracer concentration for the non-conservative tracer at times of maximum ebb tide and maximum flood tide. Figure 17-156 illustrates the effect of the zero Martinez concentration boundary condition for the non-conservative tracer. Tracer concentrations for both runs are similar along the south shoreline of the Suisun Bay. These figures indicate that after several tidal cycles, the tracer is mixed across the width of the Carquinez Strait on ebb and travels up both the north and south channels of Suisun Bay on the following flood tide. Distribution for the conservative tracer case is shown in Figure 17-157.

Figure 17-158 and Figure 17-159 present time series plots of the tracer mass in the model network for the August-September 2002 simulations. In the RMA model, a simulation duplicating the effect of the DSM2 boundary condition, the “Mtz BC=0” simulation, was implemented by setting an artificial zero-concentration boundary at the location of the DSM2 boundary. Figure 17-158 shows the tracer mass for the non-conservative tracer, for the entire “Bay-Delta”, the “Delta Only”, and for the Martinez zero concentration boundary condition. The “Delta Only” line represents the tracer mass in the Bay-Delta network that is upstream of the “Martinez BC” location. The difference between the “Delta Only” and the “Mtz BC=0” lines represents the mass missing due to a zero concentration boundary condition at Martinez. At maximum ebb, the “Delta Only” mass approximately equals the “Martinez BC=0” mass. At maximum flood, “Martinez BC=0” mass is about half the “Delta Only” mass. For a non-conservative tracer with a relatively short decay time, total tracer mass in the system comes to equilibrium at M/λ, where “M” is the mass loading from the CCCSD discharge in g/day and “λ” is decay constant in terms of 1/day.

Figure 17-160 illustrates clearly, using a set of Godin-filtered time series for the non-conservative tracer, that a significant amount of mass from the CCSD outfall is lost under the typical DSM2 boundary settings. Under these low outflow conditions, approximately 30% of the tracer mass is lost from the model. Although these simulations were run with a CCSD-only tracer, mass from locations downstream of CCSD would be lost at least these percentages.

The same time series plot for a conservative CCCSD tracer is presented in Figure 17-159. The total “Bay-Delta” mass grows linearly with time until about Aug 21, when mass begins to exit the model boundary at the Golden Gate. Figure 17-161 plots the ratio of the (Mtz BC=0) / (Delta Only) Godin filtered tracer concentrations for both the conservative and non-conservative cases. Figure 17-158 through Figure 17-161 illustrate that there is a greater relative loss of mass with a zero Martinez concentration boundary for the conservative tracer. Figure 17-161 also plots the stage time series at the CCCSD outfall location. Comparatively less tracer mass is lost with the “Mtz BC=0” condition during the neap tide period. The smaller tidal excursion during the neap tide period pushes less tracer past the Martinez boundary.

A set of tracer simulations were run for the April-May 2002 period when the NDO was higher (11,000 to 16,000 cfs). Figure 17-162 and Figure 17-163 show the time series tracer mass plots for the April-May 2002 simulation. Overall there is somewhat less tracer mass upstream of the Martinez boundary location for the non-conservative tracer for the higher NDO period (Figure 17-158 and Figure 17-162). There is visibly less tracer mass upstream of the Martinez boundary location for the conservative tracer under the higher NDO (Figure 17-159 and Figure 17-163). Figure 17-164 show the (Mtz BC=0) / (Delta Only) ratio plot for the April-May 2002 simulation period. The April-May 2002 ratios are similar to those for the low NDO period.



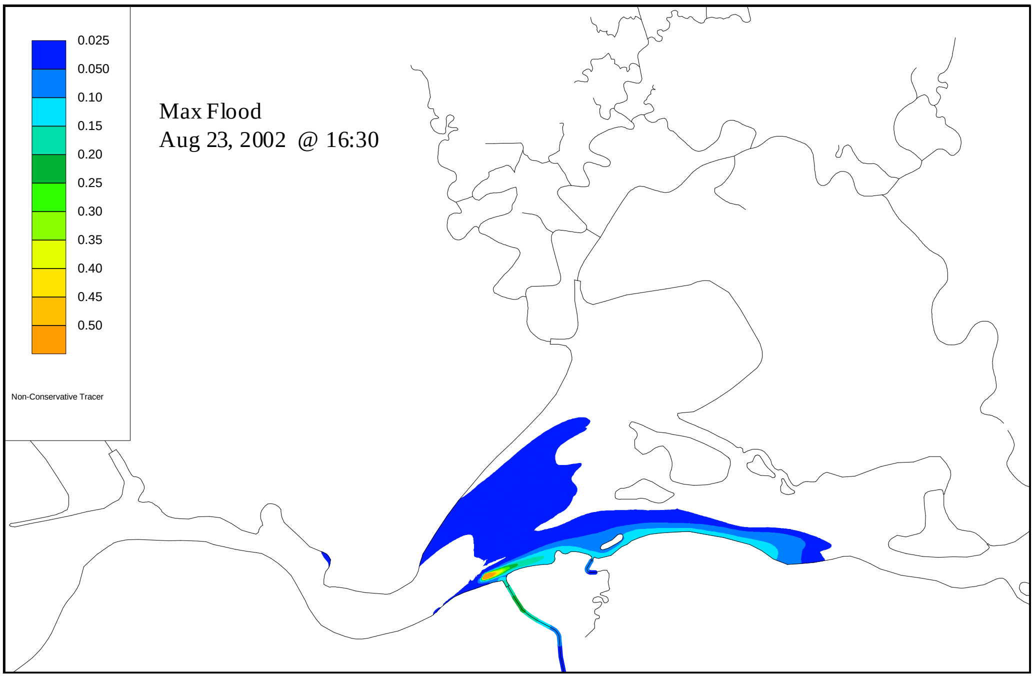
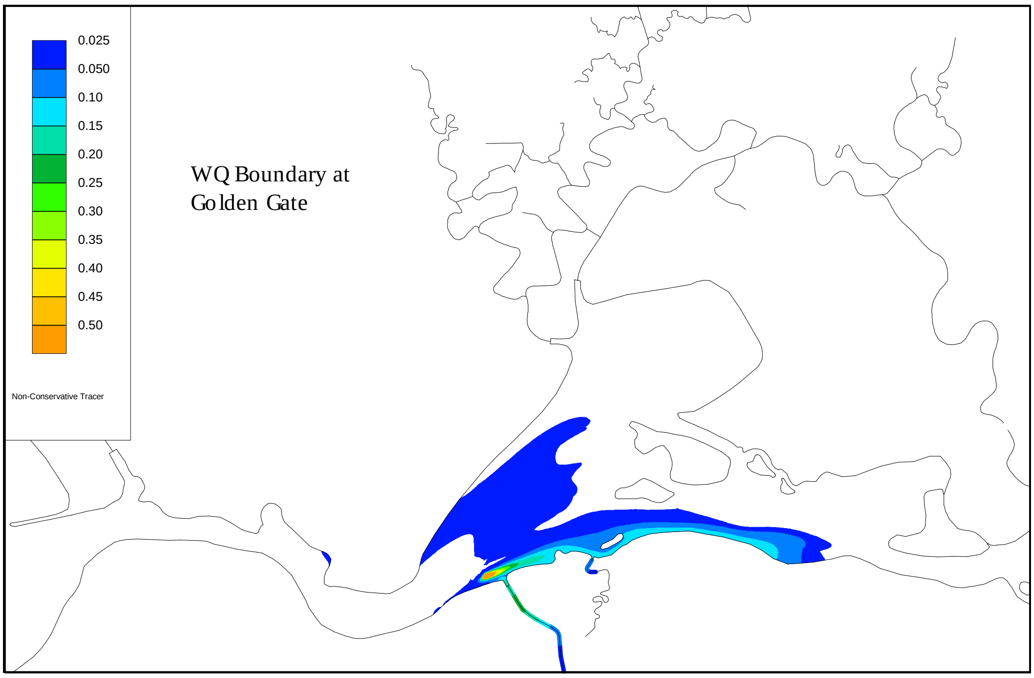


Figure 17-155 Concentration contours for a non-conservative tracer (λ = 1/day) at maximum ebb (top) and maximum flood (bottom), after one week of simulation



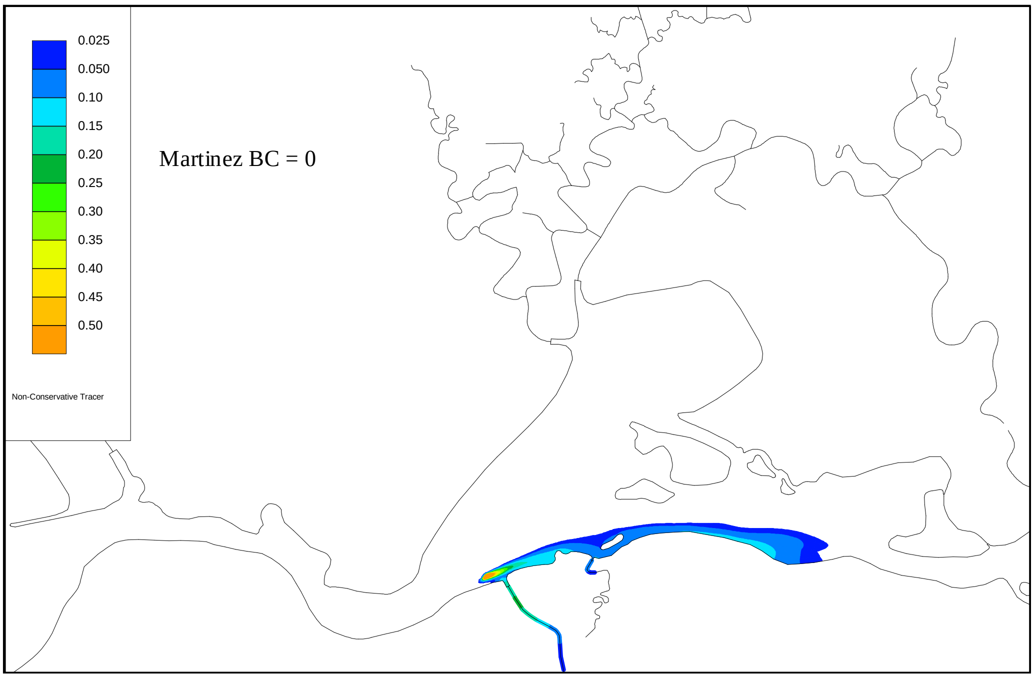
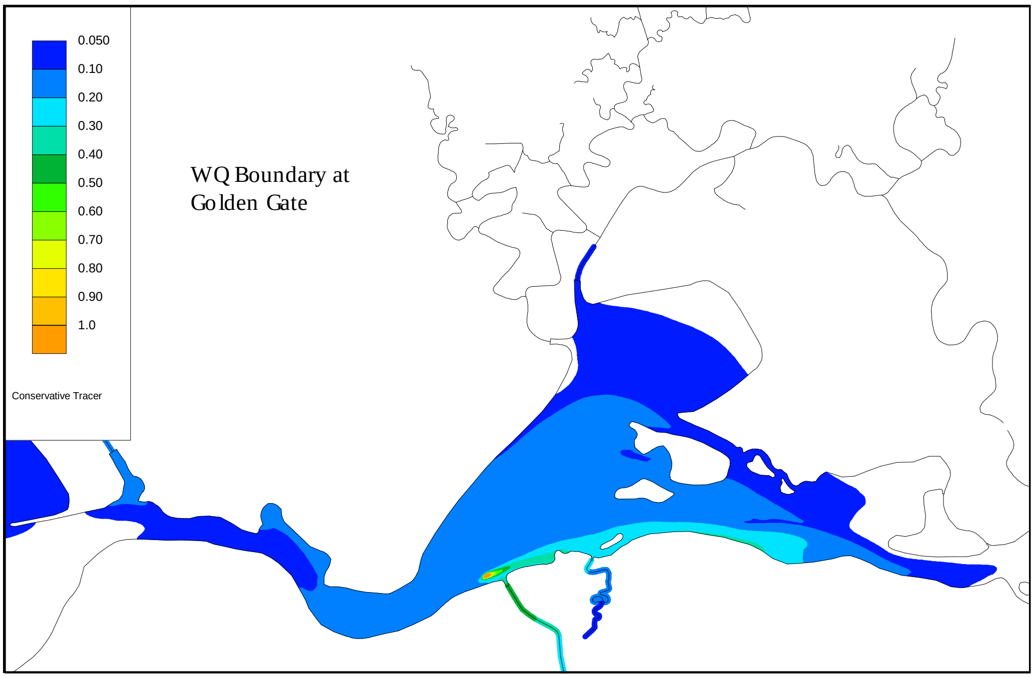


Figure 17-156 Concentration contours for a non-conservative tracer (λ = 1/day) at time of maximum ebb (Aug 23, 2002 @ 16:30) for a zero concentration boundary condition at the Golden Gate (top) vs. Martinez.



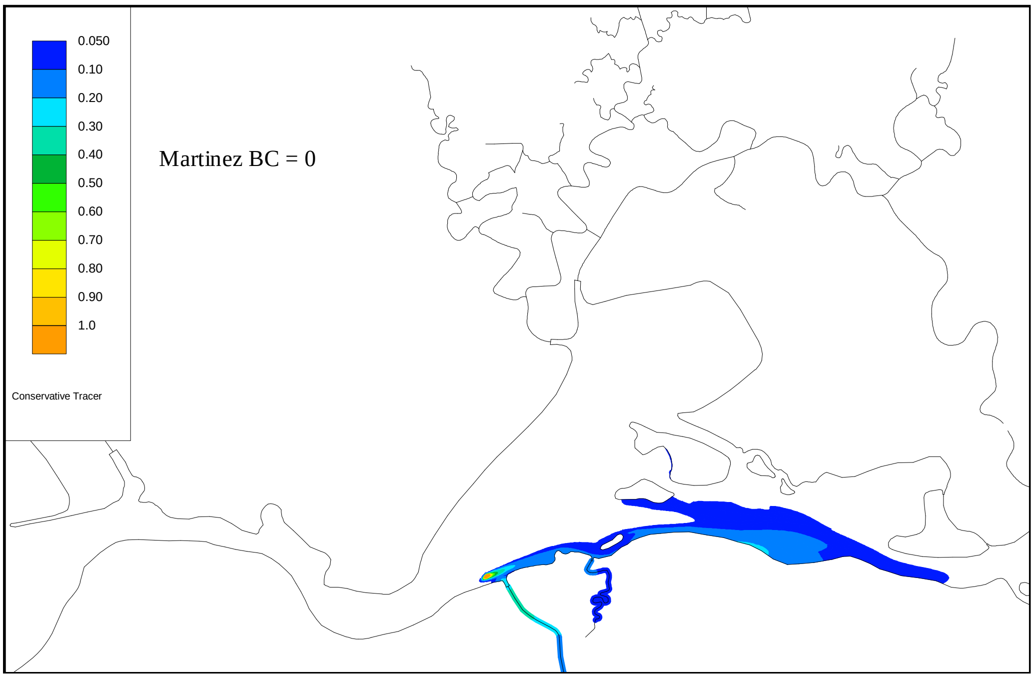


Figure 17-157 Concentration contours for a conservative tracer at time of maximum ebb (Aug 23, 2002 @ 16:30) with a zero concentration boundary condition at the Golden Gate (top) vs. Martinez.

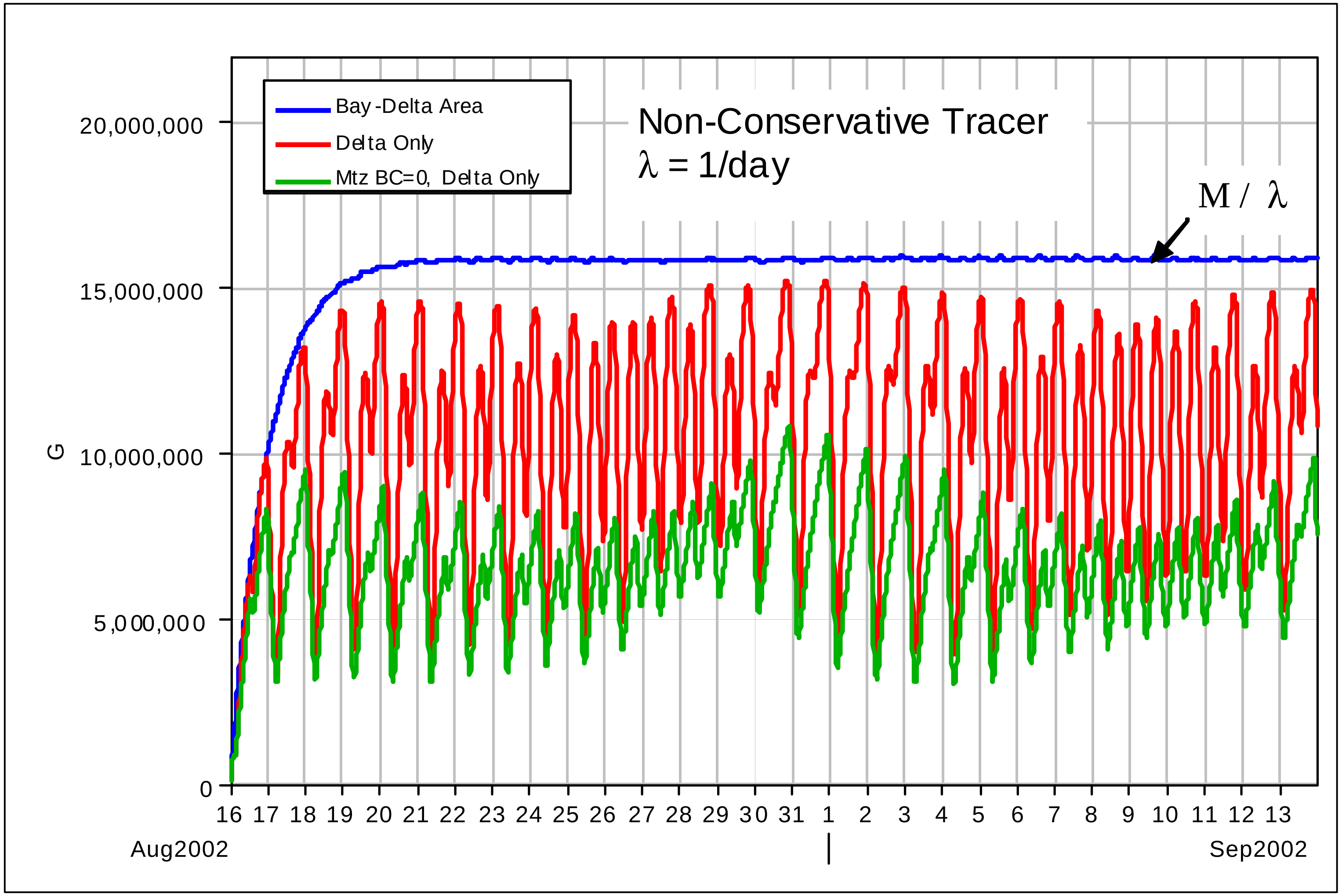


Figure 17-158 Tracer mass time series for the non-conservative CCCSD tracer (λ = 1/day). Blue line is tracer mass in the entire Bay-Delta network, red is the "Delta Only" tracer mass (upstream of Martinez), green is the "Mtz BC=0" tracer mass with a zero concentration boundary at Martinez

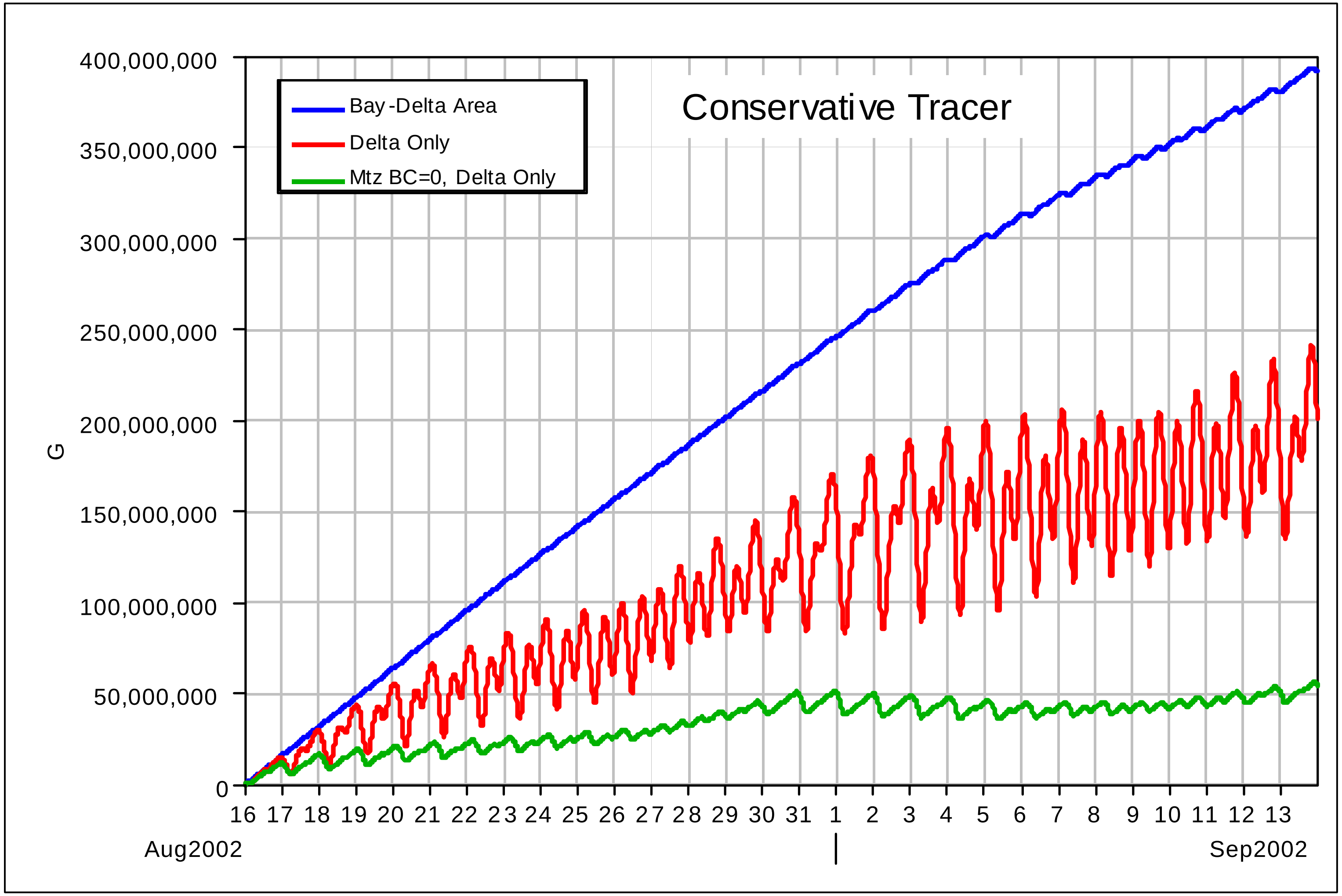


Figure 17-159 Tracer mass time series for the conservative CCCSD tracer (no decay. Blue is the tracer mass in the entire Bay-Delta network, red is the "Delta Only" tracer mass (upstream of the Martinez), green is the "Mtz BC=0" tracer mass with a zero concentration boundary at Martinez.

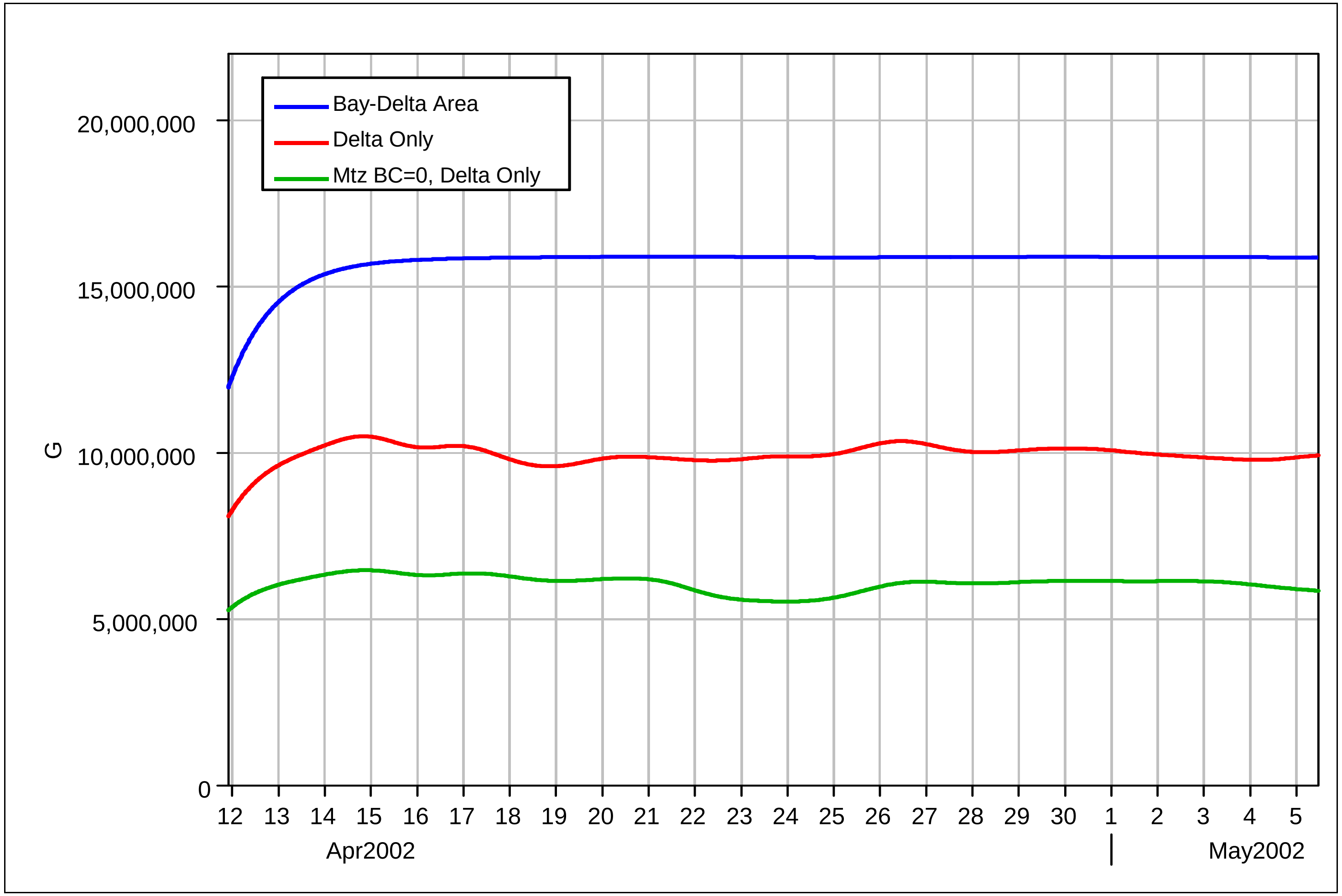


Figure 17-160 Comparison of Godin-filtered non-conservative tracer mass for three RMA11 simulations, shows that a significant amount of CCSD outfall mass and thus from all locations near the Martinez boundary, is lost under the standard DSM2 boundary condition settings.

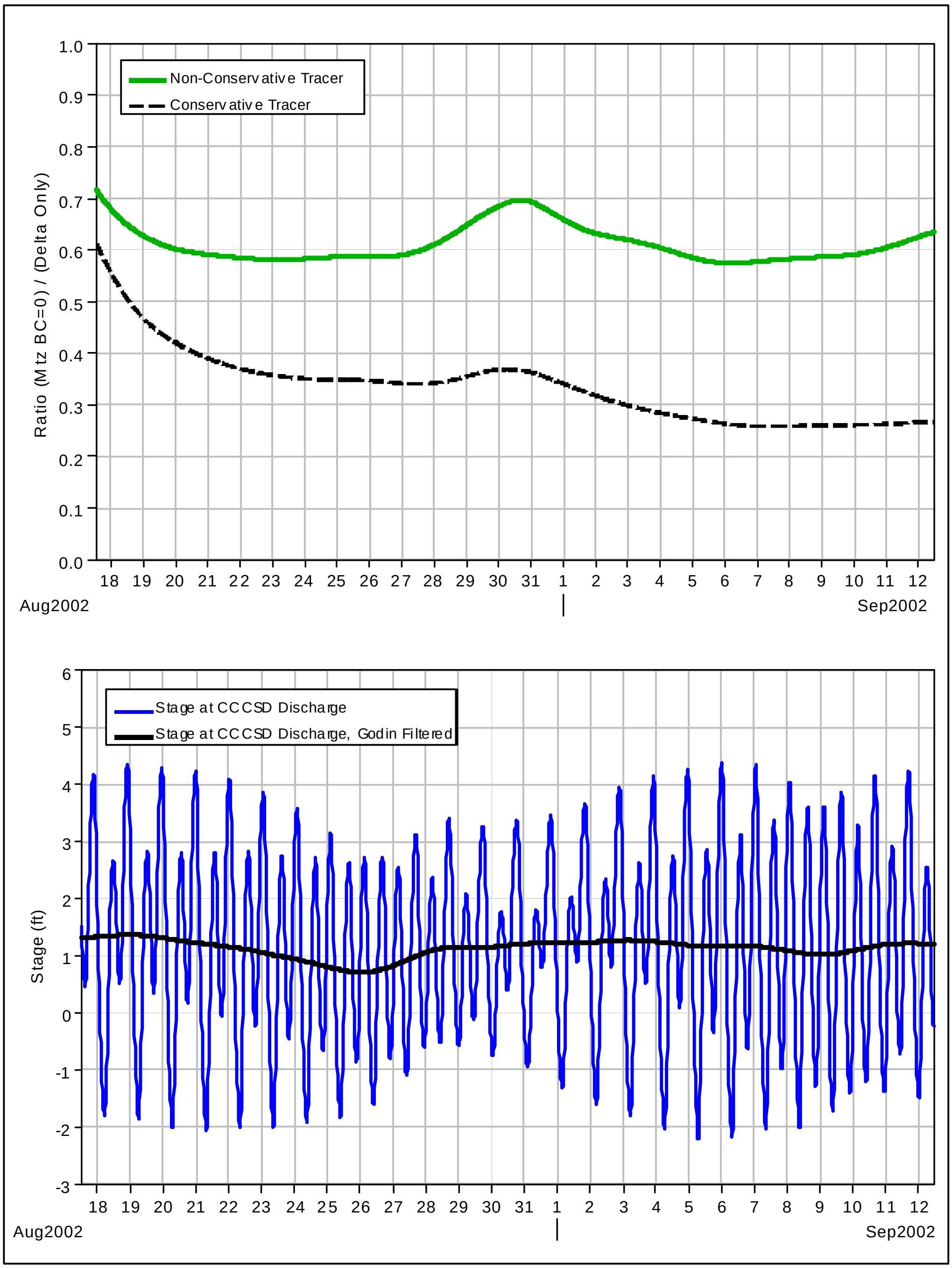


Figure 17-161. (top) Times series plots of ("Mtz BC=0")/("Delta Only") tracer mass for conservative and non-conservative CCCSD tracers. (bottom) Stage time series at the CCCSD discharge location.

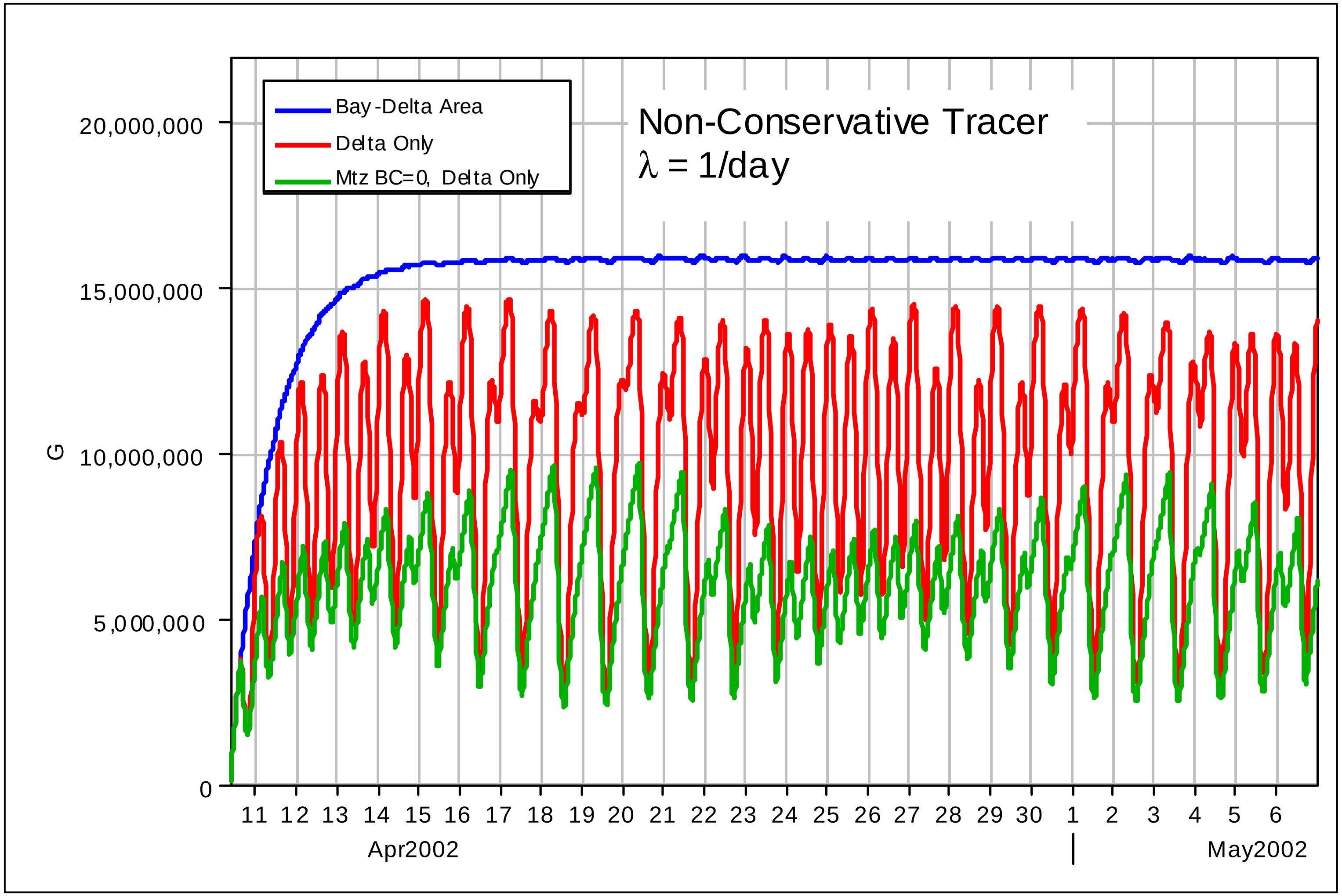


Figure 17-162 Tracer mass time series for the non-conservative CCCSD tracer (λ = 1/day). The NDO is 11,000 to 16,000 cfs over the simulation period.

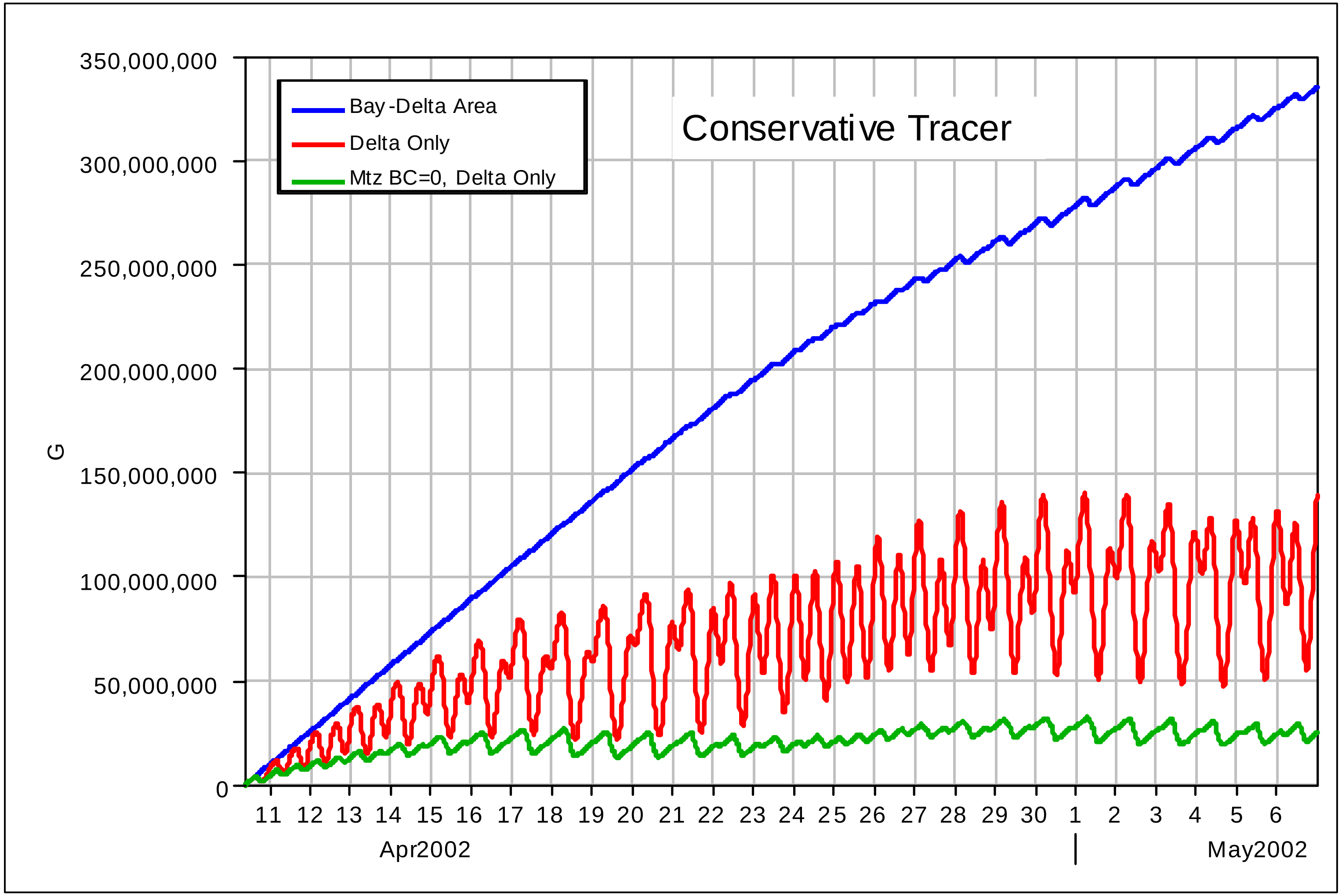


Figure 17-163 Tracer mass time series for the conservative CCCSD tracer (no decay). The NDO is 11,000 to 16,000 cfs over the simulation period.

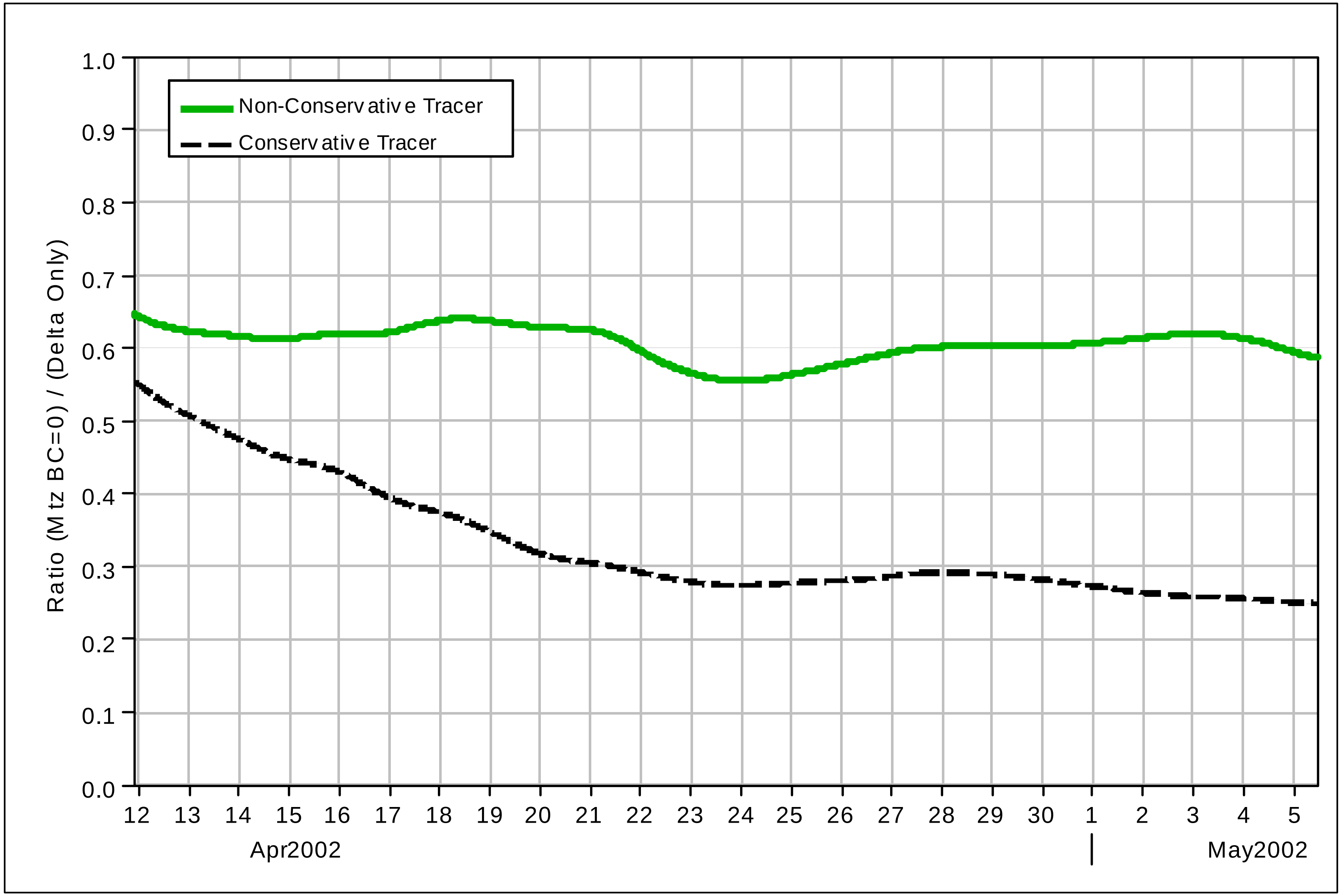


Figure 17-164 Times series plots of (“Mtz BC=0”)/(“Delta Only”) tracer mass for the conservative and non-conservative CCCSD tracers The NDO is 11,000 to 16,000 cfs over the simulation period.